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A MANUAL
OF
METALLURGY.

BY

WILLIAM H. GREENWOOD, Assoc. M.I.C.E., F.C.S.,
ASSOCIATE OF THE ROYAL SCHOOL OF MINES;
PROFESSOR OF METALLURGY, FIRTH COLLEGE, SHEFFIELD;
SENIOR WHITWORTH SCHOLAR;
ETC.

VOL. I.

FUEL, IRON, STEEL, TIN, ANTIMONY, ARSENIC,
BISMUTH AND PLATINUM.

ILLUSTRATED BY 71 ENGRAVINGS.

LONDON AND GLASGOW:
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THE AUTHOR.

PREFACE.

THE present volume is based largely upon the metallurgical syllabus issued by the Science and Art Department, and is primarily designed for the use of students preparing for the advanced stage of those examinations. Yet it has been the endeavour of the author to present to the student a condensed and succinct account of the *theory* and practice involved in the varied operations comprised in the metallurgy of those metals which are of general application to the arts and manufactures; and, while sensible of the defects of the work, he ventures to hope, that to the general student of metallurgical or engineering science, and also to those practically engaged or interested in the conduct of the numerous processes comprised under its title, it may prove to be a *useful auxiliary* to, and *résumé* of, the contents of the more voluminous, exhaustive, and expensive treatises upon the various divisions of the subject.

Much of the work must necessarily be of a descriptive character, compiled largely from the larger modern treatises and papers; and of the numerous works to which it has thus been necessary to refer, the author takes this opportunity to acknowledge his obligations especially to the very excellent, comprehensive, and exhaustive treatises of Dr. Percy, and to the author's metallurgical notes made while a student in the same gentleman's classes and laboratories at the Royal School of Mines. Amongst other works that I have perused with advantage, may be noted Bruno Kerl's *Handbuch der Metallurgischen;* Turran's *Iron Manufacture of Great Britain;* Lowthian Bell's *Chemical Phenomena of the Blast Furnace;* various papers in the *Transactions of the Royal Society*, of the *British Association*, of the *Institution of Civil Engineers*, of the *Institution of Mechanical Engineers*, the *Journal* of the *Iron and Steel Institute*, and in the pages of *Engineering.*

Throughout this volume the more modern but now almost universally adopted chemical notation, nomenclature, and atomic weights, have been adopted; but in many instances where the same body receives two or more distinct names, according to the nomenclature employed, the chemical symbol of the substance has been added, in order to facilitate its identification with the same body described under a different name in treatises adopting the old nomenclature; and, in exceptional cases, with the same object, decompositions have been represented in the two notations.

PREFACE TO THE SECOND EDITION.

A second edition of this volume having become necessary, the opportunity has been embraced to correct the few typographical and other errors of the first edition, and to revise, rearrange, and considerably extend certain chapters of the book, so as to bring the same up to date. The additions will be found principally in the chapters upon Fuel, Iron, and Steel. In the first-mentioned section considerable improvements in the *methods of coke-burning*, and the *collection of bye-products*, etc., have been effected during the past decade, and these have now been noticed in the volume. The articles treating upon the *production of open-hearth steel* have been rewritten and extended, whilst a section upon the *production of steel* by the Basic, or *Thomas and Gilchrist Process*, has been added to the work. Extensions have also been made to the articles treating upon the *production of sound or homogeneous steel ingots.*

In this manner eighty-four pages of letterpress have been added to the text and twelve new illustrations introduced into the volume, and the author thus hopes that this edition may meet with the same cordial reception in the Colleges and Technical Schools where metallurgy is taught, as was accorded to the first edition.

W. H. G.

Firth College, Sheffield.

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METALLURGY.

CHAPTER I.

INTRODUCTION.

METALLURGY.—"The art of extracting metals from their ores, and adapting them to the various purposes of manufacture."—*Percy.*

Metallurgy thus embraces a large cycle of operations of a chemical, physical, and mechanical nature; but it is with that division essentially chemical that the science of metallurgy chiefly deals, and which will form, to a great extent, the subject of the present volume—the operations of a purely physical or mechanical character being omitted or treated as briefly as possible. Thus the series of mechanical operations involved in dressing the ores, etc., belonging to the province of the miner, will not be further alluded to.

1. **Metal.**—This term was originally applied to all bodies possessing certain well defined physical characters, especially their *lustre and high specific gravity;* but at the present time the word must be taken in a more strictly chemical sense, since many bodies now considered non-metallic, as, for example, iodine, silicon, and selenium, possess many of those physical qualities formerly looked upon as the essential and peculiar qualities of the metallic state; accordingly about 50 of the *elementary* substances are classed as metals, though fresh discoveries continue to add to this number; and of these only about 15 are of sufficient importance in the arts to call for notice in the present work, viz., Aluminum, Antimony, Arsenic, Bismuth, Cobalt, Copper, Gold, Iron, Lead, Mercury, Nickel, Platinum, Silver, Tin, and Zinc.

2. Physical Qualities of the Metals.—Mercury is the only metal which, at the ordinary temperature of the atmosphere, exists in the liquid state. All others are *solid*, and all are *opaque*, except perhaps gold, which in an extreme state of tenuity transmits a greenish light; they reflect light from their polished surfaces, giving them a characteristic lustre known as the *metallic lustre*. The metals *silver*, *tin*, *cadmium*, *mercury*, *antimony*, *zinc*, *lead*, *bismuth*, etc., are *white* or *inclining* to white with bluish or yellowish tinges; *gold* stands alone as a simple metal having a *yellow* colour, and *copper* is the only *red* metal. The *specific gravity* of the metals ranges between ·58 (lithium) and 21·53 (platinum); the more *common* metals are, however, characterised by a *high specific gravity*. They differ widely in their behaviour under the influence of heat: thus some, as *tin* and *lead*, are fusible *below* redness; *copper*, *gold*, *silver*, etc., are readily fusible in ordinary furnaces; while *nickel*, *cobalt*, *manganese*, *iron*, etc., can only be fused with great difficulty; and *platinum*, *chromium*, and others are practically infusible; others again, as *arsenic*, *cadmium*, *zinc*, and *mercury*, are volatile, the former assuming directly the *gaseous* form without passing through the liquid state. The *brittle* metals may usually be obtained in well defined crystalline forms; to this class belong bismuth, antimony, zinc, etc. The *fracture* of the metals is often characteristic, and described as *crystalline*, *granular*, *fibrous*, *silky*, *columnar*, or *conchoidal*; of the first three forms mentioned, good specimens are afforded by the varieties of *iron* occurring in commerce, the *manganiferous* pig-iron known as *speigeleisen* being *largely* crystalline, *grey foundry pig* is *granular*, and ordinary *bar iron* is distinctly *fibrous*, the fracture of this latter, however, varying with the manner of breaking; *copper* affords an example of the *silky* fracture, and *tin* dropped in a fused state from a height becomes *columnar*.

3. Malleability, or "the property of permanently extending in all directions without rupture by pressure or hammering," is possessed in varying degrees by the metals; from such as bismuth, arsenic, etc., which are characterised as brittle or void of malleability, to gold and platinum, which may be laminated into leaves of extreme thinness;

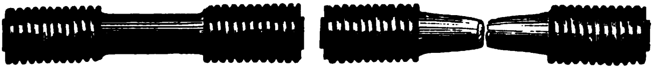
some metals, though malleable to a considerable degree, require to undergo the intermediate operation of *annealing*, *i.e.*, heating to dull redness, and then allowing to cool down slowly, this being repeated once or more during the operation of hammering or rolling out; an example of such is furnished in the case of copper. The following are in order of malleability :—Gold, silver, copper, tin, platinum, lead, zinc, iron, nickel.

4. **Ductility**, or "the property of being permanently elongated by a tensile force, or of being drawn into wire," is possessed to a greater or less degree by all malleable metals, though the most malleable are not necessarily the most ductile, the ductility of a metal being more powerfully influenced by its tenacity than is its malleability. The following is the order of ductility :—Gold, silver, platinum, iron, copper, aluminum, zinc, tin, lead.

5. **Elasticity.**—The elasticity of a metal is the extent to which it may be elongated by tension without remaining permanently extended on the removal of the strain or stretching stress; and the stress required to produce the first sensible permanent extension in a given rod, bar, or section of the metal, indicates the *limit of elasticity* of such metal. Within certain limits it is found that bars of metal, which have been strained just beyond their limits of elasticity, and which may present a slightly smaller section than the original bars, have yet assumed, under the treatment, slightly increased rigidity.

6. **Tenacity**, or "the property of resisting fracture from a tensile or stretching force," is found to vary with the purity, the molecular condition of the metal as due to its mode of treatment or preparation, and with the temperature, the tenacity usually diminishing with an increase in the temperature.

The tensile strength of a metal is also generally decreased after heating to, or above redness, and then allowing it to cool without further treatment, this is due probably to the production of a more or less crystalline structure in the metal; and often the presence of only traces of foreign metals, as for instance traces of lead, tin, and antimony in fine gold are sufficient to render that highly ductile metal quite brittle and weak under the action of a tensile force. The following are arranged in the order of their tenacity:—Steel, iron, copper, platinum, silver, gold, zinc, tin, lead.



Before Fracture. Fig. 1. *After Fracture.*

Fig. 1 is one form of the test-piece employed in determining the tensile strength of the metals.

7. **Conductivity.**—The metals, with few exceptions, rank as the best conductors of both heat and electricity. Silver, gold, copper, zinc, iron, tin, platinum, lead, antimony, and bismuth, are in the order of their conducting power for heat, while in conductivity for electricity they stand as follows: viz., copper, gold, zinc, platinum, iron, nickel, tin, lead, antimony, and then bismuth.

8. **Welding.**—Certain of the metals possess the peculiar property termed *welding*, whereby, if two clean surfaces be brought into contact and pressure applied, the two adhere together, and become part of one and the same mass; this quality is signally possessed by iron at a white heat; and lead or gold in a fine state of division, if pressed together strongly at the ordinary temperature, adhere, forming one mass.

9. **Toughness.**—Toughness, as applied to the metals, is the property of resisting fracture by bending or rolling.

10. **Softness.**—Softness, or the property of easily permanently yielding to pressure without fracture, or as being easily sectile, is typically marked in the case of lead.

The hardness of metals is usually estimated by the resistance offered or force required to draw wires of equal diameter, and of the same temperature, through a hole of a given size; thus, steel, iron, copper, silver, tin, antimony, and lead, are in order of hardness.

11. **Cold-short** is the name applied to the condition of malleable metals when they do not permit of being extended by hammering or rolling at the ordinary temperatures, without cracking or breaking at the edges, although such a metal

may be readily worked at a red heat, or at any higher temperature. On the other hand, a metal which permits of being hammered or rolled out at ordinary temperatures without fracture, but which cracks or breaks up when so treated at a red heat, is designated as *red-short*. There are some metals, notably certain inferior brands of bar-iron, which, although red-short at temperatures near redness, can be worked with facility if raised to a considerably more elevated temperature.

12. Alloy and Amalgam.—The body formed by the union or combination of two or more metals with each other is termed an *alloy*, and if one of the constituent metals be mercury, then the resulting substance is known as an *amalgam*.

The metals most likely to occur in alloys are two or more of the following, viz., antimony, arsenic, aluminium, bismuth, cobalt, gold, iron, lead, mercury, nickel, platinum, silver, tin, and zinc. Frequently, also, certain non-metallic elements, as sulphur and phosphorus, occur in bodies which are generally classed as alloys; of such is the substance known as phosphor-bronze, described in Vol. II.

13. Nitric Acid and Alloys.—If nitric acid be without action upon an alloy, there is a probable absence of all the above-named metals, except, possibly, *gold* and *platinum*.

If a reaction, attended by the evolution of nitrous fumes, follows when the alloy is treated with nitric acid, then, probably, one or more of the following metals is present in the alloy, viz., arsenic, antimony, aluminium, bismuth, copper, cobalt, iron, lead, mercury, nickel, silver, tin, or zinc, all of which, with the exception of *antimony* and *tin*, are dissolved by the acid, while the two last mentioned are deposited as white residues of their respective oxides. Hence, if a reaction ensues when an alloy is treated with nitric acid, the resulting solution will contain the above metals which are soluble in the acid, and in the presence of *large quantities of silver* the solution may also contain platinum in addition; whilst any residue, if it be white in colour, arises from the presence of antimony or tin, with only small proportions of gold or platinum, if these be present. The residue may also contain silver and lead in small proportions. A metallic powder or a black residue indicates gold or platinum, with possibly small proportions of antimony, tin, silver, or lead.

CHAPTER II.

METALLURGICAL TERMS.

14. Ore, etc.—"*Ore* is the name applied to the metalliferous matter in the state in which it is extracted from the earth by the miner."

The *ore* is usually an oxide, sulphide, carbonate, chloride, phosphate, silicate, or arsenide of the metal, or various mixtures of these, mixed with extraneous matter, often earthy or stony, as quartz, felspar, hornblende, various silicates, carbonates of lime, magnesia, etc., heavy spar or barytes, fluorides, etc., as well as portions of the rock adjoining the mineral lode; this extraneous matter is designated *vein-stuff, matrix, or gangue.*

15. Native Metals.—When the metal occurs uncombined with any other chemical element or elements, it is said to occur *native;* of such occurrences gold and platinum afford examples, though these are always accompanied by silver in small quantities.

16. Dressing Ores.—The mechanical operations necessary to prepare the material extracted from the mine for the smelting processes, are known as *dressing* operations, and consist in *breaking* the ore, *sorting*, and *washing;* operations performed with varying degrees of care, according to the value of the metal to be extracted, and to the future requirements of the smelting operations; for, as will hereafter be shown, certain proportions of *gangue* or stony matter may be useful for the subsequent separation of the metal in the furnace, by forming under the furnace conditions a fusible slag with the other extraneous matters of the ore, from which the reduced metal readily separates in virtue of its superior specific gravity.

17. Reduction.—Reduction is the process of separating the metal from its ores, or from its chemical combination. The substance effecting this separation or reduction is known as the *reducing agent.* The noble metals, gold, silver, platinum, mercury, etc., are reducible from their oxides by the application of *heat* alone, which thus becomes the reducing agent.

Carbon or carbonaceous matters, assisted by heat, are very frequently employed as reducing agents especially in the smelting of those oxides which are difficult of reduction, such as the oxides of iron, zinc, manganese, etc.; and it is notable also that, whilst these oxides are reduced as just mentioned, with the liberation of carbonic oxide, yet, if the metals themselves be heated, in contact with carbonic anhydride, to a temperature above bright redness, the metals suffer oxidation, and carbonic oxide is also liberated.

In the smelting of lead by the Flintshire process, atmospheric air and the sulphur of the ore act together as the reducing agents.

18. **Smelting.**—This is the name applied to the process, or series of processes, by which a metal or metallic compound is separated by fusion from its ore.

19. **Flux and Slag.**—Flux is the name given to the substances added to the furnace charge of ore and reducing agent, for the purpose of combining with the extraneous matters of the charge, and forming therewith a fusible compound, designated *slag*, through which the metallic particles, in virtue of their superior specific gravity, readily sink and collect beneath the layer of fused slag which collects on the surface.

20. **Regulus, Matt, and Speise.**—In smelting certain metallic sulphides, instead of obtaining, as above, merely *metal* and *slag*, it is frequently desirable, before finally extracting the metal, to concentrate the metallic matter in a fusible mass of mixed sulphides, designated as a *regulus* or *matt*, which regulus is then the object of a subsequent operation for the extraction of the metal. Similarly, if *arsenical* ores, such as the ores of nickel or cobalt, be the subject of treatment, a compound occurs similar to the regulus above mentioned, but which contains arsenic instead of sulphur, and which is then called speise. In certain operations *slag*, *regulus*, *speise*, and *metal*, may all be obtained as products of the *same* operation, occurring in layers in the order named on the bed of the furnace.

21. **Roasting and Calcination.**—These terms are often used indiscriminately to indicate operations which have for their object either the expulsion of water, carbonic anhy-

dride, etc., to volatilise or sublime certain volatile compounds, or to oxidise some portion of the ore or metallurgical product under treatment; but the last mentioned is more properly a roasting operation, whilst the two former are calcining operations. The roasting or calcination is conducted in the open air, either in large heaps or in kilns, or otherwise the ore or metallurgical product is heated in an oxidizing atmosphere, upon the bed of a reverberatory furnace.

When heaps are employed the ore is usually mixed with the necessary fuel, unless, as in the roasting of certain blackband iron ores, the ore itself contains sufficient bituminous matter to carry on the necessary combustion without the addition of any further fuel. In either case the combustible matter is ignited, and the heap of materials is then allowed to slowly burn itself out. When kilns are employed instead of heaps, then either the fuel is mixed with the metalliferous matters as before, or the kilns are arranged so as to utilise various waste gases, such as those from the blast furnaces, etc., where such are available. If the roasting or calcination be effected on the hearth of a reverberatory furnace, then the metalliferous matter does not come into contact with the fuel, as in the former cases, but the fuel is burned in a separate chamber. In any case, the object is to heat the ore, or other product, to a comparatively low and regulated temperature, with the more or less free access of air to the materials under operation.

22. **Scorification.**—Scorification is a process for the separation of readily oxidizable metals, such as tin, nickel, antimony, etc., from other metals with which they are alloyed. The operation is conducted by adding a proportion of lead to the alloy, and then heating the alloy to its melting point in a current or blast of atmospheric air. The oxides of tin, nickel, antimony, etc., are then dissolved in the litharge (notwithstanding that the oxides of tin and nickel are infusible *per se*) produced by the oxidation of the lead, and then rise to the surface as a liquid slag, which can be readily removed.

23. **Cupellation.**—Cupellation is the process by which large proportions of lead, together with smaller quantities of other oxidisable metals, are separated from *silver* and *gold* when argentiferous lead is exposed upon a suitable refrac-

tory, shallow, concave bed or hearth, to the joint action of heat and atmospheric air.

24. Sublimation.—Sublimation is the term used to designate the process of volatilizing solid substance by heat, and subsequently condensing the same in a solid state. The sublimate is often collected in the upper part of the apparatus so employed, as, for instance, in the purification of arsenious anhydride (p. 309).

25. Distillation.—Distillation, in metallurgical science, is applied to the operation wherein a volatile metal is converted into a vapour, which is subsequently condensed to the solid state, as it issues either from the bottom or the top of the distilling apparatus. In the former case the distillation is distinguished as *distillation per descensum*, as in the English method of zinc distillation, while, when the vapour passes for condensation from the upper part of the apparatus, as in the separation of metallic mercury, the distillation is *per ascensum.*

26. Liquation or Eliquation.—These are the terms applied to the process by which bodies having different melting points, or which solidify at different temperatures, are separated from one another by subjecting their mixture to a carefully regulated temperature, sufficiently elevated to melt the more fusible metal only, under which conditions the most fusible metal flows from the alloy or mixture of metals, leaving the less fusible substance on the bed of the furnace, or other liquating apparatus. Examples of this process are afforded in the metallurgy of bismuth, antimony, etc., as also in the separation of an argentiferous lead from an alloy containing lead, silver, and copper, the alloy of lead and copper requiring a much higher temperature for its fusion than does the argentiferous lead.

27. Lixiviation.—Lixiviation is an operation or process for the separation of certain metallic salts from metalliferous or other matters, by the solvent action of water or saline solutions. The operation is performed in vats or other suitable vessels, in which the dissolving fluid can be introduced upon the surface of the materials under operation, and then gradually percolate through the same. The solvent thus dissolves out the desired salt before the fluid is drawn off or runs away from the bottom of the vats. Examples of lixiviation are afforded in the wet process for the extraction of copper (p. 63, Vol. II.), and also in the fifth stage of the Augustin process for the extraction of silver (p.259, Vol. II.)

28. Cementation.—Cementation is the name applied to the process in which articles are embedded in certain powders or cementing materials, and are then heated to a temperature below fusion for a period varying between several hours and as many days. When charcoal forms the cementing material, and malleable iron bars are under treatment, then the result is a *carburization* of the iron and the production of blister steel; but if the cement powder be hæmatite iron ore, and the object for conversion be a casting of cast-iron, then the process is one of *decarburization*, and the casting acquires by the process many of the qualities of malleable iron.

29. Dessication.—Dessication is the process for the artificial drying or expulsion of water from wood, peat, etc., without destroying the organic tissue. It is effected either by exposing the materials to heated air, by centrifugal action as adopted in peat drying, or by other means.

30. Dissociation.—This term is used to denote the phenomenon occurring at elevated temperatures, by which certain compound gases are resolved into their constituent elements under the influence of heat alone. Thus the dissociation or resolution of water vapour into its constituent elements, oxygen and hydrogen, is effected by heat alone at a temperature of 2500° C.; and so also carbonic anhydride (CO_2) is resolved into carbonic oxide (CO) and oxygen at a temperature of from 1000° C. to 1200° C.

31. Occlusion of Gases.—Occlusion denotes the phenomena presented by certain metals, by which they are able, at elevated temperatures, to absorb many times their own volume of a gas. This property is possessed by molten silver, which, at the temperature of fusion, occludes many times its own volume of oxygen (p. 222, Vol. II.). Iron and steel occlude, in like manner, hydrogen and nitrogen (p. 205).

32. Caking.—Caking and binding are terms used indiscriminately to denote the quality in coal whereby, when strongly heated out of contact with the air, its particles more or less strongly cohere to form a solid mass known as *coke*, whilst coals which do not possess this quality are described as *free-burning*, or *non-caking*.

33. Rusting.—This is the term applied to the process of slow oxidation and waste, which goes on at the surface of metallic iron when the same is exposed to the joint action of air and moisture, or more rapidly if carbonic anhydride be also present. The hydrated oxide so produced is known as *iron-rust* (see author's *Steel and Iron*, p. 42).

34. Annealing.—This is an operation usually performed on plates, castings, blocks, etc., of such materials as are unduly hard or brittle, either from irregular cooling, hammering, rolling, or otherwise working the material at a *critical temperature*, and whereby local strains, etc., have been set up within the mass, of a nature which allow at least of a partial correction by annealing, *i.e.*, again heating the article to about a cherry-red heat, and subsequently cooling under suitable conditions. In the case of iron and steel the cooling is effected either by allowing the body to cool very slowly within the furnace itself, or by withdrawing it from the furnace, and then immediately covering it with ashes or other bad-conducting material, under which it is allowed to cool down to the ordinary temperature before it is removed.

In the case of crucibles for steel-melting purposes, the term "annealing" is applied to the operation by which the crucibles are slowly warmed up and finally heated to redness before they are inserted into the melting-hole or fire.

35. Annealing Furnace.—The annealing furnace used for the annealing of the large crucibles used in steel melting is a rectanguler chamber of brick-work (see fig. 52), the fire-bars of which are placed close together and form the bed; the front of the furnace is closed by an iron door *z*, which moves vertically upwards and downwards, while the furnace communicates with the atmosphere by a small flue or stack in its roof. A layer of fire to the depth of a few inches is laid over the whole surface of the bars, and this is covered with small cinders or coke, the pots are then packed in mouth downwards, the whole being then covered with small coke. The front is now closed, and the whole is left for from 12 to 20 hours, when the pots will be thoroughly dry, at a red heat, and ready for insertion into the melting furnace.

36. Fining and Refining.—These are the terms generally applied to those stages of a metallurgical process, in which the foreign metals and other impurities are finally eliminated; but in special cases, as in the treatment of pig-iron for the production of malleable iron, the term *fining* is applied to that stage of the process wherein the *decarburization* is principally effected (p. 155), whilst the term *refining* is applied to a preliminary stage, in which a partial decarburization of pig-iron, and its conversion into white or plate metal (p. 155) only is effected.

37. Shingling or Nobbling.—These terms are applied to the operations to which the puddled ball is subjected under the hammer, helve, press, or other squeezing apparatus, for the expulsion of slag, cinder, and scoriæ from the puddled ball, and the welding together of its white-hot particles into a comparatively solid mass, called a *bloom.*

38. Rabbling.—Rabbling is the term used to designate the process of moving about, or stirring the charge upon the hearth of a reverberatory furnace. The straight, square, or round iron bar usually employed for this purpose is called a *rabble;* a similar bar, but flattened at one end, is called a *peeler*, and is used for introducing and distributing pigs of metal, or other substances, over the furnace hearth.

39. Slags.—The slags occurring in metallurgical furnaces, with only few exceptions, such as those produced during the smelting of lead ores, are *anhydrous silicates,* of which the most frequent are the silicates of lime, magnesia, alumina, iron, and manganese, with small quantities of potash.

Blast-furnace slags are usually regarded as silicates of lime and alumina, and have a composition approximately represented by the formula $2Al_2O_3,3SiO_2 + 6(2CaO,SiO_2) = Al_4Si_3O_{12} + Ca_{12}Si_6O_{24}$, whilst the slag of the refining furnace is represented by the formula $2FeO,SiO_2, = Fe_2SiO_4$.

The slags produced in smelting operations are generally *grey, blue, green, brown, red,* or *black* in colour, and often present a veined or marbled aspect. They are either glassy or dull and opaque, according to the rate at which they have been cooled; if cooled quickly, the slag may be brittle and glassy in appearance, while, if cooled slowly, the same slag may be dull, opaque, and often tough.

The colour of the slag is generally due to the presence of metallic oxides, but in the case of certain charcoal furnaces smelting iron ores, the blue colour of the slag is probably due to the presence of manganous sulphide.

The fusibility of slags also depend upon their composition; thus, whilst ferrous or manganous oxides generally increases the fusibility of a slag, magnesia decreases the fusibility, and so, when dolomitic (magnesian) limestone is added to the blast furnace the fusibility of the slag is reduced, and there is a tendency, at the same time, to produce white pig-iron in the furnace.

40. Clays.—Clays are essentially *hydrated* silicates of alumina, with varying amounts of iron, lime, magnesia, potash, etc., along with more or less mechanically mixed silica; but the proportions of silica and alumina present in clays apparently the same, and coming from the same locality, are found to differ widely. Clays owe their plastic quality to their chemically combined water. Clays which will withstand exposure to a high temperature without melting or sensibly softening are described as *fire-clays;* such occur largely in the carboniferous, and more sparingly in other geological formations. The fire-clay employed for the manufacture of *crucibles* or *fire-bricks*, should contain only a very small proportion of alkali, and be free from iron pyrites (FeS_2).

41. Crucibles.—"This term is usually applied to such open mouthed movable vessels, in which bodies are exposed to high temperatures, as are movable by tongs."

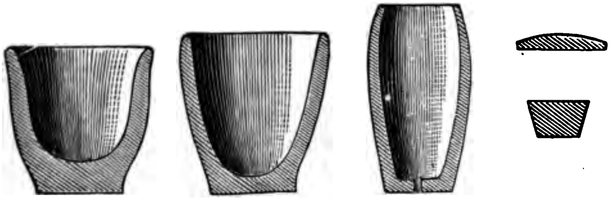
Good crucibles should be capable of resisting a high temperature without sensibly softening, should not be tender while hot, ought to stand sudden and great alternations of temperature without cracking, and resist the corrosive action of materials such as litharge, etc., and the action of the fuel.

Crucibles are made of mixtures of fire-clays, burnt clay, silica (sand), graphite, coke-dust, and ashes; the burnt clay being usually the old pots (crucibles) freed from adhering slag, broken and ground up, its admixture assisting in the prevention of the cracking of the crucibles on drying, which occurs if raw clays only be used. Mixtures of clays are preferred for making crucibles: thus, for the crucibles used in the melting of steel, a common mixture consists of Stourbridge-clay, china-clay, blue-clay, ground pots, and coke dust; the ingredients are ground fine, so as to procure uniformity in the size of the particles, then mixed on the floor, water thrown over it, and the mass kneaded by the workmen treading it barefooted for several hours, the clay being turned over with the spade at intervals; the mass is then cut up and weighed into portions called *balls*, each sufficient for one pot (crucible); each *ball* is worked by hand on the table or bench before being finally moulded into form, an operation performed either by a machine or in a mould by hand. The crucibles are now transferred to shelves around the steel-house, where they remain about a fortnight before using, so as to be thoroughly dried; and before their final use for melting purposes, are annealed for from 15 to 18 hours in a separate furnace, from which they are removed while still hot and inserted in the melting furnace. These pots hold about 50 lbs. of bar-iron cut into small pieces.

The small crucibles used by assayers, etc., are kiln-burnt.

Plumbago crucibles contain only so much clay as will suffice to give the mixture of clay and plumbago the necessary plasticity; the plumbago is hand-picked, ground, and sifted before mixing with the clay. These crucibles withstand a higher temperature without softening than do the clay crucibles, also greater alternations of temperature without cracking; their surface is also smoother, and particles of metal do not cling to their sides.

Cornish, *London*, and *Hessian* crucibles are smaller crucibles used by assayers, differing only in shape, and made from mixtures of fire-clay and sand. Accompanying are sketches of London, Cornish, and steel melting crucibles.



Cornish Crucible. London Crucible.

Scale, $\frac{1}{5}$.

Crucible, Cover, and Stand employed for melting cast-steel—*Scale*, $\frac{1}{16}$.

Fig. 2.—Crucibles.

For making certain assays, as, for instance, the dry assay of an iron-ore, it is necessary to have a crucible with a carbonaceous lining, or, as it is technically called, a *brasqued* crucible. This *brasque* may be made either of wood-charcoal and starch, of gas-carbon mixed with coal-tar, or, for the small iron assay crucibles, a good lining may be made by a mixture of ground charcoal and treacle; the inside of the clay crucible is lined with this mixture, pressed moderately hard, and the crucibles, covered over to prevent the ready access of air to the lining, are heated to redness; when gases cease to escape from the decomposition of the treacle, the crucibles can be taken from the muffle or furnace, and when cold are ready for use.

42. Fire-Bricks.—The qualities already stated as required to constitute a good crucible, apply also to the case of *fire-bricks.* In the manufacture of fire-brick, the fire-clay is ground between rolls or under-edge stones, kneaded with water, and moulded like ordinary bricks, then thoroughly dried and baked in closed kilns. They must always be set in a mortar of fire-clay, and not in the usual lime mortar, otherwise, at the intense heat to which they may be subjected, chemical union would occur between the free mechanically mixed silica of the clay, and the lime of the mortar with the production of a fusible silicate, and consequent rapid destruction of the structure.

43. Dinas Brick.—This is an exceedingly refractory brick used for the roof of reverberatory furnaces, etc.; it presents a rough hackly appearance or fracture from the presence of fragments of white quartz embedded in a yellow matrix. The material of these bricks occurs in the Vale of Neath, and contains about 97 per cent. of silica, the remainder being alumina, oxide of iron, lime, alkali, and water. The bricks are made by mixing the ground or crushed rock with from 1 to 3 per cent. of lime. The mass is then moistened with water, and pressed into iron moulds of the form required; they are then carefully dried and heated in kilns for about seven days.

44. Silica Bricks.—The *silica bricks* made by the Landore and other companies,* and used for the roofs, ports, etc., of the Siemens' open-hearth steel-melting furnace, are similar or identical with the above bricks. Silica bricks expand considerably on heating, and they also require to be set or laid in a mortar of silica sand and water only. Lime or clay mortar cannot be used in conjunction with silica bricks, since it would, at the high temperature of the Siemens' furnace, combine with the silica of the brick, and produce a fusible slag, which would thus rapidly destroy the furnace.

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* *Steel and Iron* (Author).

45. Silica Sand.—The *silica sand* used as the mortar in the setting of silica bricks, and also employed for making the bottom of the open-hearth steel-melting furnace, and for mixing with fire-clays in the manufacture of certain fire-bricks. has a composition analogous to the silica rock just described, whilst the sand forming the pig-bed as also that used for moulding purposes, is much less siliceous in its character.

46. Ganister.—Ganister is a refractory siliceous rock, usually containing just sufficient argillaceous matter to hold or cement together its siliceous particles upon the application of a little pressure, as by ramming, etc., without any further admixture of clay, or other binding material.* Ganister is used largely for lining the melting holes (described p. 218) for the crucible steel process, as also for the lining of the ordinary Bessemer converter.

47. Dolomite.—This is a highly basic magnesian limestone; it is highly refractory, but contracts on heating to whiteness to about one half of its original volume; hence, in using this substance it is necessary, before making it into bricks or otherwise applying it as a furnace lining, to well burn it, so as to expel carbonic anhydride, and also to prevent as far as possible the great contraction just mentioned as arising when the material is strongly heated. Dolomite is now used (mixed with coal-tar as a cementing material) for the basic lining of the Bessemer converter in the so-called basic process for the production of steel.

48. Bauxite.—Bauxite is a hydrated aluminous ferric oxide, containing some 60 per cent. of alumina, with about

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* *Steel and Iron* (Author).

20 per cent. of ferric oxide, and only from 1 to 3 per cent. of silica. Bauxite is highly refractory, so that when calcined and made into bricks, with an addition of some 6 or 8 per cent. of clay or plumbago to act as a binding material, it then yields a very durable and practically infusible brick.

49. Ash.—Ash or ashes is the mineral residue left behind upon the combustion of solid fuels.

50. Clinker.—Clinker is the more or less perfectly fused residue or ash left on the fire-bars of furnaces, burning coal, or other solid fuel, and often contains particles of unconsumed coal, cinders, etc., besides the imperfectly fused earthy matters of the fuel.

CHAPTER III.

FUEL.

THIS term is applied to all those materials which are practically employed for the generation of heat.

The fuels used in all furnace operations, *i.e.*, *anthracite*, *bituminous*, *caking*, *cannel*, or other kinds of *coal*, *peat*, *lignite*, and *wood*, or their derivatives, as *coke*, *charcoal*, etc., are all of *vegetable* origin. The elementary constitution of the fuels will accordingly be much the same, though the relative proportions of the elements differ widely; these elementary constituents are *carbon*, *hydrogen*, *oxygen*, *nitrogen*, and *inorganic* or *earthy* matter. The last mentioned constitutes the *ash* of the fuel, and varies in amount from 1 per cent. to 4 per cent. in wood, and from 1 per cent. to 20 per cent. in the denser fuels.

But besides the above bodies of organic origin generally employed as fuels, there are in special metallurgical operations, as in the ordinary and in the basic Bessemer process for the manufacture of steel, other elements, such as the *silicon* and *phosphorus* in pig-iron, which are practically used for the generation of heat, and ought accordingly to be classed amongst the bodies employed as fuels in metallurgical operations. The *sulphur* in copper and iron pyrites is also, by its combustion, capable of providing an amount of heat that can be utilised, entitling this element to be classed, therefore, as a fuel. In the producer gases (p. 61), the hydrogen produced by the decomposition of water vapour, is also employed as a heat producer.

51. Wood.—Wood cannot be used as the fuel where high temperatures are required, owing to the large amount of water it retains, unless it has been previously kiln-dried; timber which has been felled and exposed to the atmosphere for a considerable time, so as to become thoroughly air-dried, still retains about 20 per cent. of water. Hence, for metallurgical operations, the wood to be available as a fuel must first be converted either into charcoal, or subjected to dessication or drying at a temperature which is almost sufficient to char the wood.

CLASSIFICATION AND COMPOSITION OF MATERIALS OF VEGETABLE ORIGIN WHICH ARE USED AS FUELS.

			Average Approximate Composition of the Dry Fuel, exclusive of Ash.			
			Carbon.	Hydrogen.	Oxygen.	Nitrogen.
1. Wood,			50	6	43·0	1·0
2. Peat or Turf,			59	6	42·5	0·5
3. Coal,	Lignite, or Brown Coal,		70	5	24·5	0·5
	Bituminous Coal,	Non-caking, rich in oxygen,				
		Caking,	82	5	12	1·0
		Non-caking, rich in carbon,				
	Anthracite,		95	2·5	2·5	Trace.

PRODUCTS OF THE CARBONIZATION OF FUELS.

	Solid Fixed Product.	Volatile Products.
1. Wood,	Charcoal,	Water, wood-spirit, pyroligneous acid, oils, tars, ammoniacal compounds, hydrocarbons, carbonic oxide, and carbonic anhydride.
2. Peat or Turf,	Peat charcoal,	Water, tarry matter, oils, ammoniacal liquors, carbonic oxide (CO), hydrogen, and hydrocarbon gases.
3. Coal,	Coke,	

The woods most commonly employed as fuels are sycamore, birch, deal, ash, elm, oak, fir, larch, etc. The earthy matter or ash of this class of fuel contains potash, soda, lime, magnesia, a little oxide of iron, silica, phosphoric acid, sulphuric acid, and chlorine, but is marked by the absence of alumina.

52. **Peat** is the product of the slow decay without access of air of various kinds of plants, in this country especially of the mosses; but like wood it retains water sufficient to render it unavailable for the production of high temperatures. Even after cutting into squares and piling so as to thoroughly air-dry it, peat still retains from 20 to 40 per cent. of water; this class of fuel also contains an excessive amount of inorganic matter, the ash frequently amounting to 10 or even 20 per cent. of its weight. The *ash* contains potash, soda, lime, magnesia, alumina, oxide of iron, phosphoric and sulphuric acids, chlorine, silica, and silicates; the lime in some cases amounting to 36 per cent., and the oxide of iron to 15 per cent. of the total weight of the ash. It is also noticeable that whereas the ash from peat contains *alumina* and *oxide of iron*, that from wood is void of *alumina*, and contains but a trace of *oxide of iron.*

53. **Coal.**—The different varieties of coal form by far the most important class of substances employed as fuel.

Coal is a solid mineral substance, more or less combustible, of a dark brown or black colour, opaque, except in very thin slices, brittle, infusible without decomposition, not sensibly soluble in ether, benzol, or solvents of resinous matters; the percentage of carbon is greater than that in peat or wood, and the proportion of oxygen to hydrogen in the fuels exists here at the minimum, the ratio increasing in the different varieties of fuel as they approach nearer to the characters of wood, in which the ratio has its maximum. For during the decomposition and solidification of the vegetable matter necessary for the formation of coal, gaseous products, as marsh gas (CH_4), the fire-damp of the miner, along with other hydrocarbons, carbonic anhydride (CO_2), etc., are emitted (either slowly and quietly, or, if accumulated under pressure, sometimes escaping with violence); and in this manner the oxygen and hydrogen of the original vegetable matter is more or less completely removed, according as the change from wood to coal is more or less complete, until, as in anthracite, *carbon* may form 95 per cent. of the entire mass.

Sulphur is always present in coals, either as sulphate of lime and iron pyrites, or in combination with the organic constituents of coal; *silica* and *alumina* also are invariable components of the ash of coal.

The *lignites* are brown, brownish-black, or black in colour, with a dull or shining lustre, either wood-like, earthy, or compact in structure; they are non-caking, and differ from other varieties of coal in the large proportion of water, amounting to 15 or 20 per cent., which they retain after air-drying; oxide of iron, silica, and alumina form the chief ingredients of their ash.

Bituminous coals mostly burn with a more or less smoky flame; certain varieties of the class, when heated, swell up and become pasty, becoming eventually, if the heat be continued without the access of air, converted into a hard coherent mass termed *coke*, and are hence described as *caking* coals; other varieties, heated under the same conditions, either split up or retain their form without the particles cohering together, these latter are described as *non-caking* or *free-burning* coals.

The *bituminous* coals contain more hydrogen and oxygen than the anthracites, and thus stand between them and the lignites in chemical composition.

Anthracite has a stronger lustre than bituminous coal, and, as already mentioned, contains a much greater proportion of carbon than any other class of coal, this element forming 90 per cent. of the fuel; it contains very little volatilizable matter, and burns only with considerable difficulty, requiring a much stronger draught for its combustion than the other classes of coals, but in its combustion generates an intense local heat, and is hence much used in melting operations. It decrepitates and crumbles away when thrown upon a hot fire, and is non-caking.

Coals often contain a notable quantity of foreign minerals, as *sulphides*, *oxides*, etc., of copper, iron, arsenic, antimony, lead, etc.

54. Charcoal.—When wood is heated to about 300°C. out of contact with the atmosphere, or with only a limited supply of air, it suffers decomposition; the more volatile products, as oils, tars, ammoniacal compounds, volatile hydrocarbons, etc., distil off and may be condensed; at the same time another portion of the oxygen, hydrogen, and carbon escape as carbonic anhydride, carbonic oxide, and carburreted hydrogen, along with hydrogen and other permanent gases, and there remains behind a more or less porous carbonaceous residue called *charcoal*, retaining the original form and structure of the wood, and which consists essentially of the carbon of the wood along with its fixed or inorganic constituents, as also a little oxygen and hydrogen from which it cannot be freed by heat. The charcoal is more or less compact according to the temperature at which the carbonization has been effected.

Charcoal is a bad conductor of heat and electricity, its conductivity being increased the higher the temperature at which it has been prepared. Its specific heat is ·2411; its specific gravity varies with the nature of the wood and mode of carbonization, but ranges between ·106 and ·203; when burnt, charcoal leaves from 1 to 5 per cent. of ash.

The yield of charcoal varies with the mode of preparation, heat, and rapidity of carbonization, as well as the nature of the wood operated upon, and varies accordingly from 50 per cent. to 75 per cent. by volume of the wood from which it is produced, or from 15 per cent. to 25 per cent. by weight. The yield is greater the lower the temperature of charring the wood, thus the average yield by rapid charring is 14 per cent., and reaches 23 per cent. if carbonized slowly.

The wood for charcoal burning should be of mature growth and felled during winter; rotten and worm-eaten wood is bad, and timber is deteriorated for charcoal burning if long soaked in water.

For blast-furnace or forge purposes the charcoal is better if kept for some months previous to using.

55. Mode of Preparation.—Charcoal burning is effected either in heaps, stacks, or piles in the open air, in pits, or in closed chambers of brick, stone, or iron, heated either by the combustion of the volatile products of the distillation of the wood itself, or from a separate source of heat applied externally to the chamber, as by superheated steam, etc.

56. Charcoal Burning in Piles.—For this purpose a suitable piece of ground, level and sheltered from the wind, is selected, clayey ground being avoided. Three stakes are then driven vertically into the ground (see fig. 3), which are to form the chimney of the pile at the commencement of the operation, the billets of wood are then arranged in nearly vertical and concentrical rows around this chimney, the billets leaning slightly inwards so as to be self-supporting. The spaces between the billets are filled up by the smaller branches and twigs of the trees; two or three rows in vertical height are thus built up, forming a large conical heap, the top being formed by a quantity of the smaller pieces of timber laid transversely, and so tying the pile together. The surface is now covered closely over with turf, the latter being plastered over either with *breeze*, *i.e.*, small charcoal, or with charcoal and earth, at every part except the opening at the top (formed by the three stakes first mentioned), and a few openings left around the base of the pile for the admission of air. The space between the three stakes previously cited is now filled with small and more easily inflammable twigs; when these are ignited, the combustion rapidly extends to the wood in its vicinity. In the first or sweating stage much water appears in the covering and at the base of the pile; when this is over the cover is made tight, and the combustion proceeds from the top to the bottom, and from the centre to the outside of the heap. Vents are made as the process

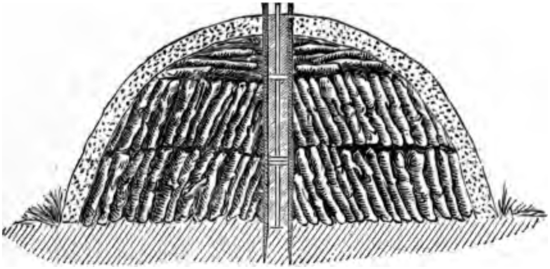

Fig. 3.—Circular Pile for Charcoal Burning.

proceeds at varying heights around the pile, commencing at first near the top, and these are closed in succession as carbonization in that region or zone is supposed to be completed, judging by the smoke which issues from the vents so made; the smoke at first is thick and white, becoming, as the process approaches completion, thinner and pale blue in colour, with occasionally a blue flame appearing. The vents in this region are then closed, and a series lower down in the pile made, and so on until the whole pile is carbonized; as the process proceeds, any sinkings that may occur from the unequal burning of the wood are filled up by removing the cover at the part and inserting fresh wood. Combustion being completed, the pile is covered with ashes, and left to cool for two or three days; it is then taken to pieces, beginning at one side, the portions still hot are quenched by throwing water or sand upon them.

In another method of burning, instead of the billets being arranged in vertical rows around the centre, they are laid horizontally around the central stakes or chimney (fig. 4).

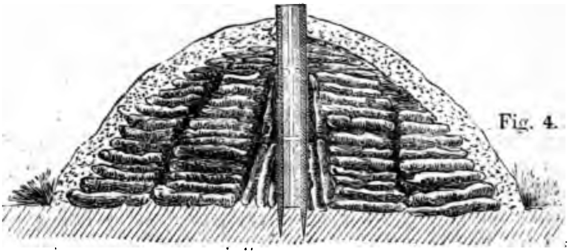

Fig. 4.

In other modes of charcoal burning in piles, the wood is cut into lengths of about 8 feet, and these are laid transversely on the ground so as to form a rectangular pile 24 feet long, and increasing from a height of 2 feet at the lower end to 7 or 9 feet at the other; the sides of the pile are formed by planks supported by props or stays; the space between the wood to be burned and these planks, is rammed with moistened "breeze" or small charcoal, the top of the pile being covered with leaves and faggots (see fig. 5). The pile is lighted at the lower end, and as the process proceeds holes are opened and closed at different points, as described for the previous method, commencing at the lower end and proceeding towards the higher, until when the higher end is in active operation, the lower end will have ceased to burn, and be cooling down.

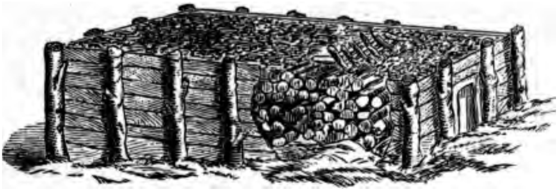

Fig. 5.—Rectangular Pile for Charcoal Burning.

The zones of active carbonization during the process of charcoal burning in piles are tolerably well marked; thus, if the accompanying (fig. 6) be a section of the circular pile, it is lighted along the axis AB, and a row of vents opened along the surface at E, E, etc.; the air entering at the base takes the most direct and easiest course towards the vents, which will necessarily be through the mass of wood contained in the zone described by the revolution of EMAB around the vertical axis AB; since the mass of material between the chimney AB and the line EM will consist of the timber which has been dried and partially charred by the burning material introduced down AB, and so having a less volume than the original wood, there will be larger cavities or spaces between the pieces, and the air entering at the bottom, MM′, will thereby find less obstruction through this part than other portions of the pile, and so carbonization proceeds most rapidly in this zone or area; the vents at E now being closed and others opened at F, F, the material between EM and FN is under the same relative condition that existed

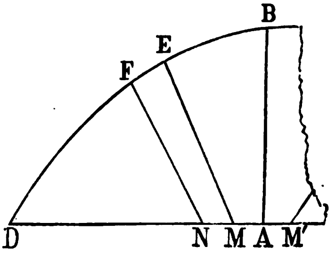

Fig. 6

between AB and EM when the operation commenced; that is, the wood is dried and imperfectly charred from the heat developed by the carbonization of the previous zone, so that carbonization will now proceed in the area described by the revolution of the plane EMNF around the axis AB, the inclination of ME, NF, etc., to AD becoming successively less and less, *i.e.*, approaching at each step nearer and nearer to coincidence with the plane of the base of the pile; the carbonization thus proceeding from the centre towards the circumference of the pile.

In rectangular piles the process is much the same, the stack being ignited at the end A (fig. 7), and vents opened at E, decomposition proceeds in the area AMEB; when the openings at E are closed and others opened at F, the products of combustion, no longer having exit along EB, pass up through the section EMNF, completing the carbonization in this area; the vents in the same manner being closed at F and others opened at G, and so on successively to H, etc.; the inclination of the boundary of the active zone, EM, FN., etc., continually approaches, as before, more and more towards horizontality.

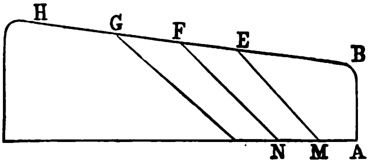

Fig. 7.

The heat necessary for the conduct of the operation is, to a large extent, derived from the combustion of the volatile products of the decomposition of the wood, and also, no doubt to a small extent, by the actual burning away of a portion of the charcoal itself.

The method of charring in retorts or in closed chambers is generally pursued where the tar and pyroligneous acid escaping during the process are to be collected. For this purpose the retorts are heated externally, and the volatile products of the carbonizing process are conducted by pipes from the retorts to receivers placed below the floor. In some districts also it is the practice to collect these by-products, even when the charring is effected in heaps or piles, in which case the base of the pile is constructed of masonry, built so as to slope from all sides towards a central well or dish, towards which all the volatile matters flow, and from which the volatile and condensible products are conveyed to a suitable condensing apparatus.

Where *kilns* are employed in charcoal burning, they are either rectangular, cylindrical, or conical in form; of these, the first is simply a rectangular chamber enclosed within four brick-walls, all well tied together by wrought-iron tie rods, and the whole is closed in with an arched roof, whilst an upper and a lower door or opening is made in each of the end walls. The upper doors serve for the introduction of the wood to be charred, whilst the lower ones are for the withdrawal of the charcoal. In the lower part of the side walls are a series of vent-holes for the admission of the air required for combustion, and for the escape of the volatile products produced during the carbonization. A chimney is formed in the centre by suitably arranging the wood as it is charged into the kiln, and into this chimney are introduced shavings, etc., for lighting up the kiln. After lighting-up, the doors are all luted with mortar, when, as in pile burning, the escaping smoke is at the commencement dense and yellow in colour, but as the condensible products of the distillation cease to be evolved, the smoke becomes less dense and bluer in colour when the vents are successively closed, a stage reached about the fourth or fifth day after lighting up. When the process is completed the vents are all closed, and a further period of rest of from four to eight days are required for cooling down the charge.

The *round kiln* is either quite cylindrical or slightly coned upwards, and it is covered in with a spherical domed roof, its construction otherwise being similar to that of the rectangular kiln just described. The conical form, as being more economical, is rapidly superseding both the circular and the rectangular kiln for charcoal burning. *Conical kilns* are built of from 25 feet to 35 feet in diameter at the base, and from 20 feet to 25 feet in height; the cone of the walls being either made regular from top to bottom, or a very much flatter cone forms the roof, and stands upon the steeper cone which forms the body of the kiln. Doors for charging, and vent holes for the admission of air, are left as in the previously described forms, and altogether the process is conducted as before described, but the conical form requires less bracing, and is altogether less costly to erect.

57. Peat Charcoal or Coke.—This product does not appear to be adapted to metallurgical purposes, its extreme friability rendering it unsuited for bearing any superincumbent pressure such as exists in blast furnaces, etc. It has been proposed to prepare peat charcoal by reducing the peat to pulp, forming the pulp so obtained into blocks, subjecting these blocks to pressure, and then carbonizing by the action of superheated steam; but the process has not been commercially successful.

58. Coke.—Coke is the carbonaceous residue left on the destructive distillation of coal, etc., and consists essentially of carbon, with the fixed earthy or inorganic constituents of the coal from which it is produced, retaining also a small proportion of oxygen, hydrogen, and nitrogen, and as occurring in commerce, it contains from 2 per cent. to 6 per cent. of water.

The average composition of coke, exclusive of ash, is

Carbon	=	97·33
Hydrogen	=	·35
Oxygen	=	2.32
		100·00

Coke varies much in both its physical and chemical characters, depending upon the mode of coking and the quality of coal employed. It varies in colour from grey to black; some specimens are dull, while others are almost metallic in appearance, and sometimes iridescent; like wood charcoal it varies much in density, and it may be light, porous, and tender, or dense, hard, and resisting; the higher the temperature employed in its production, and the longer it is exposed to the heat, the harder, more dense, and, at the same time, less easily combustible will the coke become. The *yield* is also influenced by the temperature employed in its production, the higher the temperature employed the greater will be the yield; this may possibly be affected to a limited degree, by the decomposition of hydrocarbon vapours, tar, etc., arising from the distillation of the coal in the lower part of the pile. Such vapours ascend through the superincumbent heated mass, are decomposed, carbonized, and deposit their carbon as a lustrous coating on the coke, while only their hydrogen is burned off. At the same time the particles of coal are soldered, as it were, together into one mass, rendering the coke more dense, whilst the coal also tends to swell during the same period, but being confined by the side walls of the kiln, a pressure is thus exerted which renders the coke harder and more silvery white in colour. An increased yield can only occur from this cause when the temperature is sufficiently high to effect the decomposition of these vapours.

59. Coking in Piles.—This operation is conducted in circular piles of from 18 to 30 feet in diameter at the base, and from 5 feet to 6 feet at the chimney. In forming a stack of this kind, a chimney is first erected by placing four bricks in the form of a square, though not in contact, erecting short columns on these, and then completing the chimney by placing bricks across the corners of each other, so as to leave spaces between the ends of each brick for the passage of gases, etc. This chimney is closed either with a tile, or has a cast-iron damper applied as required. The large coal "lumps" are then stacked around and leaning towards this centre chimney, outside of which again is placed the smaller coal. The pile thus built up is covered over to within a foot of the base with small coke dust; and live coals are now placed near the top of the chimney, the combustion rapidly extending downwards to the coal of the stack; thick smoke appears and issues through the covering; and as this smoke is replaced by the blue flame of carbonic oxide, the attendant applies coke-dust to that portion of the pile, and so checks or stops the combustion in that region.

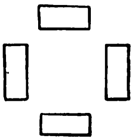

Fig. 8.

When the thick smoke has been succeeded by plate and transparent gas and blue flame in every part of the pile, which occurs about the fifth or sixth day after firing, the chimney is perfectly closed, and the whole surface is plastered over with wet coke dust. The pile is then left to cool down, and on about the tenth day it is watered and the coke drawn.

60. Coking in Kilns.—The kilns consist of two parallel walls A, A, 5 feet in height, and built about 8 feet apart inside, with

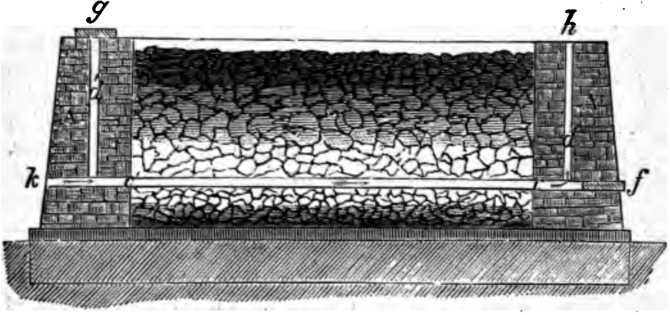

Fig. 9.—Rectangular Coking Kiln.

inner faces of fire-brick. In these walls, at intervals of about 2 feet in the direction of their length, and at the same distance from the ground, are left transverse openings *c*, *c'*, those on opposite sides being kept in a line with one another; from each of these ascends a flue *d d'*, etc., to the top of the wall, these channels serve for regulating and directing the current of air through the kiln; as shown in the sketch, the current is entering at *k* and passing out at *h*, since the other openings at *f* and *g* are stopped by tiles, and thus, by inserting the tile *f* at *k*, and removing *g* to the opposite wall *h*, the direction of the current will be reversed; and by stopping all the four openings the entrance of air through this section of the kiln is prevented. To charge the kiln, one end is bricked up, and through the other coal slack is wheeled, then watered and stamped into the bottom of the kiln to the level of the flues *c*,*c'*, etc.; stakes of wood are now inserted transversely across the kiln from each of the openings *c*,*c'*, reaching into the openings in the opposite walls. Coal is then wheeled in, watered, and stamped down as before, until the whole space between the walls is filled; the end is now bricked up, and the top covered with coal dust or loam, when the stakes of wood are withdrawn, leaving channels through the mass. Into each of the flues on one side of the kiln is inserted readily inflammable sticks which are ignited; then supposing these sticks inserted at the side *c*′, then the damper is placed at *g*′ and in *f*, so as to direct the flame in the direction of the arrow, in the course of a few hours the fire will have extended across the kiln, the plates are then removed from *g* and *f* and placed at *h* and *k*, so as to direct the current in the reverse direction; the direction of the current is now regularly changed after every two to four hours according to the weather, unless the coking on one side be observed to be proceeding more rapidly than on the other, in which case the flues are kept open longer on the one side necessary to regulate the process. In about eight days a white flame escapes from the flues, and the process is judged to be completed; the whole of the openings are now closed, and in about two days longer the fire will have died out, when the end walls are taken down, and the coke drawn.

61. Coking in Ovens.—Coke ovens differ much in their size, form, and construction; the ordinary oven is a circular, rectangular, or oval chamber of fire-brick or other refractory material, in which coal is subjected to a process of dry distillation. The circular or bee-hive oven is a building of about 10 ft. in diameter at the base, and about 5 ft. high. Around the floor of the oven a wall about 19 in. high is raised, from which springs an arch or dome of brickwork, having an opening at its summit which forms the opening for the introduction of the coal in charging, and also acts as a chimney during the coking operations (the floor of the oven is about 3 feet from the ground, so that trucks may be run up to the oven and the coke raked out into them); around this structure are built four thick walls of rough stone, forming the whole into a square block, the corners between these walls and the circular building being filled in with sand, rubbish, etc., so as to exclude air from the oven, and give greater stability to the structure; while in one end of the oven is a doorway or opening, bricked up loosely during the coking operations, and through which the charge is withdrawn. The charge of about two tons of small refuse coal being introduced and spread over the floor by iron rakes, the end opening is loosely bricked up, so that only sufficient air may obtain access to the interior for the combustion of the volatile products; the oven being hot from the working off of a previous charge, decomposition quickly commences, and in two or three hours it is necessary to plaster over the greater part of the doorway with a mixture of wet soil and sand to check the admission of air, the combustion becoming too vigorous; and after about twenty-four hours the door is entirely plastered over; in twelve hours longer the flame which has been issuing from the chimney at the top of the oven disappears, and the chimney is stopped with stones and earth; when, after standing twelve hours longer, the coke is ready for drawing. These ovens, when in fire, work continuously night and day.

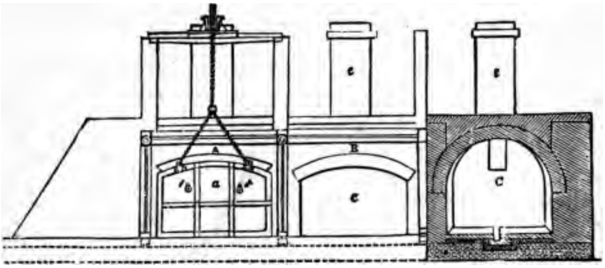

Fig. 10.—Front Elevation and Cross-section of Rectangular Coke Ovens.

Fig. 10 shows at A a front elevation of the chamber of one of a range of rectangular coke ovens, whilst at B a second chamber is shown with the door closing the oven removed, and at C is a cross section behind the door of a third oven in the same range. Fig. 11 shows a longitudinal section of the same ovens. The sides of the ovens open out from the back towards the mouth or door *a*, while the bottom also inclines slightly from the back to the front, so that when the coking operation has been completed, the whole charge is readily drawn out at once into the space in front of the ovens. For facilitating the withdrawal of the coke, a drag-bar is placed upon the floor of the empty oven before commencing to charge in the coal, whereupon the charge of about 4½ tons of small coal is brought in hopper trucks along a tram road which runs over the top of the ovens for the full length of the range. The contents of the trams are discharged through the openings *d* into the chamber of the stove. The coal is then distributed fairly evenly over the bottom, until the oven has been quite filled when the aperture *d* is closed. The oven being hot from the working off of a previous charge, decomposition of the coal rapidly ensues, and the door *a* is luted around to prevent the too free admission of air and the too rapid a rise in the temperature. As described in the last paragraph, during the earlier stage of the process flame issues copiously from the chimneys *e*, one of which is built at the rear end of each oven, but the flame becomes less luminous, and disappears as the process proceeds. The progress of the coking is observed through the sight-holes at *f, f* in the front door, and in the latter stages of the process the charge gradually sinks, until after about 70 hours the coking is completed, when the door *a* is raised, and the whole charge can be withdrawn by connecting the end of the draw-bar with an endless chain which runs in front of the ovens, and is worked by an engine fixed at one end of the range of ovens.

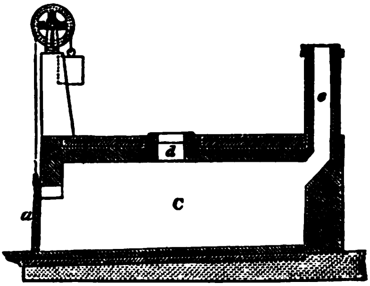

Fig. 11.—Longitudinal Section of Rectangular Coke Oven.

The coke is still hot, but it is immediately cooled by directing a stream of water upon the mass, and it is at the same time broken up by the workman previous to its removal from the coke-bank to the blast-furnace or to the trucks.

As noted at page 36, the *yield* of coke as also its hardness and resistance to crushing, are greatest when the temperature attained during its production has been highest, and the time of coking the shortest; hence the plans proposed by Cox, Brodie Cochrane, and others, for heating the air required for the combustion of the gases, and at the same time suitably admitting and regulating the supply of heated air to the top of the oven so as to obtain the highest temperature without consuming any of the coke itself.

In the Brodie Cochrane oven the only air admitted to the oven first circulates through a series of flues in the circular roof of the oven, before it is finally admitted through horizontal openings or ports at one side of the oven into the body of gas above the charge. The products of combustion, etc., then pass out from the opposite side of the chamber by a flue to the chimney and without striking the body of coke within the oven.

Cox's coke oven is constructed with the view of retaining as much as possible of the heat produced during the coking operation, and utilizing the heat so stored up for working off the succeeding charge. For this purpose the ovens, built in two rows back to back, with a chimney between each pair, have a double roof consisting of two arches, the one above the other, with a space between the two, through which the gases pass from the coking chamber proper before reaching the chimney; on the second or upper arch is placed a considerable mass of sand or grit for still further increasing the mass of material to extract the heat from the escaping gases. The coking chamber is nearly rectangular, but slightly wider at the front end than at the rear, and the floor inclines from the back to the front, this form being adopted to facilitate the withdrawal of the coke; this chamber is bricked up at the rear end, and closed at the front end with a movable door, swung as an ordinary furnace door; at each side of, but exterior to the chamber and opening to the front, is an opening communicating by a channel in the brickwork with the back of the furnace, where three holes open from it into the coking chamber; these openings are for the admission of air, which is thus drawn from the front, but only obtains access to the oven after passing along the heated sides to the back, whence the heated air entering the chamber passes forwards, and then returns through the space between the two arches, and so to the stack. The charge introduced at the mouth of the chamber or oven is spread to a uniform depth, and the door is then closed and luted; the amount of air drawn through the oven being regulated by a damper in the stack. The coking being completed, the product is quenched by injecting water into the oven, after which the coke is drawn out in one mass by a drag inserted at the charging of the oven, and which only requires coupling to an external arrangement of mechanism to draw the mass bodily from the oven.

62. Collection of the By-products from Coke Ovens.—Many coke ovens such as those described in the previous pages are still at work, but it will be noted that no provision is made in them for the *collection of the waste or by-products*, tar, oils, ammoniacal liquors, etc., which are always more or less produced during the carbonization of coal, and which are now in most new works collected, and meeting with a ready sale, form an additional source of revenue to the coking department. It is to be noticed that the high temperature and quick carbonization, such as is pursued in gas-works, yields the largest proportions of gas and of by-products, but the coke produced is inferior and quite unfitted for most metallurgical requirements. On the other hand, the slow carbonization carried on in the coke-ovens has for its first object the production of a dense, lustrous, and strong coke, such as is required for furnace purposes, hence both the proportion and the nature of the by-products differ materially in the two classes of operations even when operating on similar classes of coals.

Of the methods proposed and in practical operation for collecting the by-products from coke ovens, that of Mr. Jameson has at least the merit of great simplicity, inasmuch as the oven may be constructed practically upon the ordinary bee-hive or other type, except that special care should be observed that the oven does not draw air from the bottom. For this purpose it is best to form a foundation 18 or 20 in. beneath the bottom of the oven, of some such impervious material as cement or pitch, but the material selected must be unaffected by the heat at this depth, below the mass of heated coke in the oven. Upon this foundation the ordinary oven is constructed, except that in the centre of the bottom there is formed a shallow well, from which radiate towards the circumference of the bottom, a number of channels or drains.

the well and channels being each covered with perforated quarls. The well itself is connected with a series of pipes, mains, and a condensing apparatus, through which the gas and by-products are drawn by the gentle suction of a fan, blower, or engine. In the suction pipes thus arranged the tarry oils and ammoniacal liquors collect in considerable quantity, whilst the gases may be passed forward and burnt under steam boilers, or, as in the *Otto* arrangement, the gas may be returned to the oven for combustion, after having passed through the condensing apparatus.

The coking operation thus proceeds with the Jameson arrangement exactly in the opposite direction to that which goes on in the ordinary bee-hive oven, for in the latter the gases and vapours all rise to the surface of the charge in the oven and there suffer decomposition, whilst with the Jameson arrangement the gases and vapours descend and escape from the bottom of the oven through the suction apparatus. It is necessary accordingly that the suction be only gentle, and always insufficient to draw air through the mass of incandescent coke or coal within the oven, otherwise considerable loss in the yield of coke may result.

Other methods of collection are described in conjunction with the Simon-Carvès and other coke ovens.

63. The Simon-Carvès Coke Oven.—In this oven the coal is carbonized at a high temperature in comparatively thin layers. The ovens are closed chambers heated from the outside by the combustion of the gases generated within the ovens themselves, and for this purpose the gases are burnt within a series of flues, which traverse along the sides and beneath the bottom of each coking chamber. No air enters the oven, and there is thus no loss of coke from combustion at the surface of the charge, and the yield of these ovens is for these reasons about 15 per cent. higher than is produced in the ordinary bee-hive ovens.

The Simon-Carvès ovens, figs. 12 and 13, consist of long, high, and narrow brickwork chambers K. These are built together in groups, with horizontal winding flues A.A., formed in the division walls. The flues A.A. communicate, as shown by the arrows in fig. 12, with two horizontal flues B.B., which pass beneath the bottom or floor of each chamber. The flame and products of combustion from the fireplace C first traverse the bottom flues B.B., and then ascend to the uppermost of the side flues A.A.; from thence they circulate backwards and forwards along the sides of the coking chamber until they finally pass out, as shown, to the flue F, which conveys the gases either under steam boilers or direct to the chimney. At one end of each oven, and beneath the floor level, is a fire-grate C with its ash-pit *m*. The fire-grate is closed by doors, and the gases resulting from the distillation of the coal within the oven after having been drawn off through the aperture E and the valve G, are separated in the condensers, etc., from the tarry-oils and ammoniacal liquors with which they are accompanied. They are then returned to the ovens and admitted to the fireplace C through a nozzle introduced into the fire-door from the pipes *n*. The gases are thus at once ignited as they pass over the burning fuel on the fire-bars, and the resulting flame traverses the bottom and sides of the oven in the manner

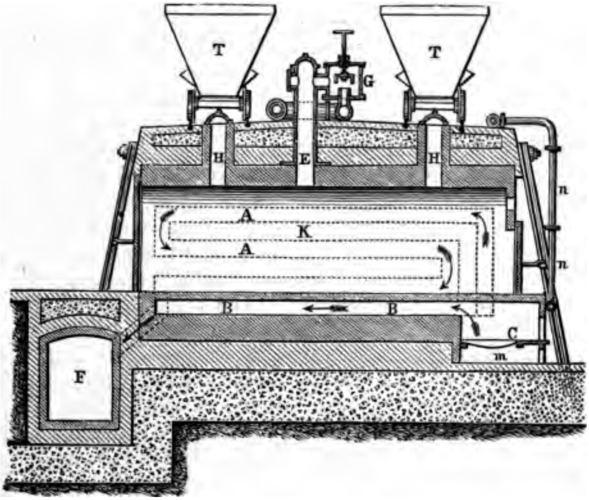

Fig. 12.—Longitudinal Section of the Simon-Carvès Coke Oven.

already indicated. The fire on the bars C serves only to ignite the gases as they enter the coke oven flues, and hence the grate only requires firing about once in 12 hours. Recently the temperature of the oven has been further increased by introducing heated air (heated by the waste heat of the flues) for the combustion of the gases around the oven.

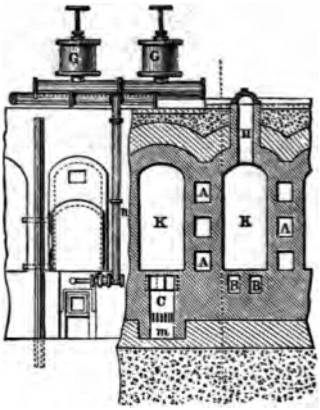

Fig. 13.—Front Elevation and Cross-sections of Simon-Carves Coke Oven.

The coal for coking is brought to the ovens in hopper trucks T, T, and is charged into the oven in the same manner as with the bee-hive oven, through holes H in the roof of the same. When the total charge has been thus introduced the charging holes H are closed by covers, which are then luted down. The doors closing the ends of the ovens are also carefully luted, to prevent the admission of air during the coking process.

The separation of the tar and ammoniacal liquors from the volatile products produced during the carbonization or distillation of the coal is effected in these ovens by drawing off the gases from the ovens by an exhauster through the pipe E, and then passing them through a series of pipes cooled by water. In these pipes the oils and condensible products are deposited, whilst in passing through scrubbers filled with moistened coke the ammoniacal liquors are separated (the ammoniacal compounds after conversion into ammonic sulphate are sold for artificial manure). The uncondensed combustible gases pass onwards, however, from the scrubbers, and are returned for combustion in this case by the pipes *n* to the ovens themselves, whilst the products of their combustion are subsequently passed forwards and are used for raising steam, etc.

64. Appolt Coke Oven.—In this oven, as in the Simon-Carvès last described, and in the Coppee oven described in the next article, the gases from the ovens are burnt on the outside of the coking retort or chamber, instead of in the inside as with the older form of bee-hive, rectangular, Cox's, and other ovens.

The Appolt oven is chiefly in use on the Continent, where, as in Belgium, such ovens are built with 18 compartments in each block, and the ovens then yield about 16½ tons of coke or 80 per cent. of the coal introduced during the day of 24 hours. For use in these ovens the coal before coking is carefully crushed and washed for the separation of sulphur and phosphorus.

The Appolt oven, as just stated, consists of twelve or eighteen vertical retorts, chambers, or ovens of brickwork, arranged in two rows of six each; each oven is surrounded by an air-space of from 7½ to 10 in. in width, and the chambers themselves are taper, measuring about 1 ft. 1 in. by 3 ft. 8 in. at the upper end, and 1 ft. 6 in. by 4 ft. at the base or lower end; each retort is provided with a cast-iron door at the bottom, serving to close its lower end, and which door opens downwards into an arched vault or chamber running the whole length under each row of six retorts, into which the coke falls when this door is allowed to fall open at the end of the coking operation. The twelve retorts of this oven are contained within four walls of brickwork, between which and another massive brick wall, forming the exterior of the whole kiln, is a space filled up with loosely pulverized non-conducting matter, which allows of the expansion and contraction of the brickwork within as the coking operations proceed. The air-spaces surrounding each of these vertical chambers communicate with one another, forming one large divided chamber which also communicates, by means of openings left in the brickwork, with the interior of the retorts themselves; the gaseous and volatile products of the decomposition of the coal obtain in this manner access to this outer chamber, where their combustion is effected by admitting atmospheric air through holes in the outer sides of the kiln or oven; the products of combustion passing along flues left in the long side walls of the oven to the stacks, of which there is one to each row of six retorts.

The oven being heated from a previous charge, the coal is introduced at the top, the cover of the oven is then luted on with clay or coke dust; decomposition is immediately set up by the contact of the coal with the heated walls, and the gases escaping into the surrounding chamber are there burnt, the heat thus developed being sufficient to maintain the temperature of the oven sufficiently high to carry on the carbonization or coking continuously. In twenty-four hours after introducing the charge the carbonization is complete, the coke is drawn from that compartment, and the compartment or retort immediately recharged. If the oven is not already heated from previous working, it is necessary to insert temporary bars into the bottom of each compartment or retort and introduce a moderate fire, which is kept up for eight or ten days; the gases pass through the air-spaces, and so heat the walls of the oven; after this time the oven has attained the proper temperature of 1200° C. to 1400° C. and is ready for charging with coal for the coking process.

In this oven it will be noticed that the products of combustion are burnt on the exterior of each compartment, and not in the interior of the vessel, as in Cox's and most other coking retorts.

65. Coppee Coke Oven.—This oven is much like the Appolt oven, except that instead of the tall vertical retorts of the Appolt arrangement, the Coppee chambers or retorts are long and narrow but high, and are built horizontally. The Coppee chambers each measure about 29 feet 3 inches in length by 17 inches in width and 4 feet in height, for ovens in which the coking is completed in 24 hours; but they are made somewhat wider and higher when 48-hour charges are to be worked. In all cases the ovens taper from back to front in order to facilitate the withdrawal of the charge of coke. These ovens are built in ranges or groups of about 30 each, as shown in fig. 14, but they are coupled and worked together in pairs. Each chamber is fitted with two doors at either end; of these, the lower ones *k* measure about 3 feet in height, whilst the upper ones *l* are only 1 foot in height.

The chambers A,A′, whilst still hot from the last charge, are each charged as rapidly as possible with about 3 tons of *washed* and *crushed* small coal, introduced from hopper trucks through three openings in the roof of each retort.

The charge is distributed uniformly over the bottom by rods, which the workman introduces through the upper end doors of the ovens. The coke is withdrawn from each retort of every pair A, A', and the retort recharged with coal when the charge in the other retort of the same pair is about half coked. After charging a retort, the openings in the roof are covered over with suitable covers, which are then luted around the edges, whilst the end doors are also all carefully luted around to prevent the admission of air to the fuel within the oven. Distillation at once ensues, and the volatile products pass out from the coking chamber through a series of 28 openings a, a' in the roof of each chamber, and descend by a corresponding number of vertical flues b, b'. Standing over the vertical flues b, b' is a sort of chimney

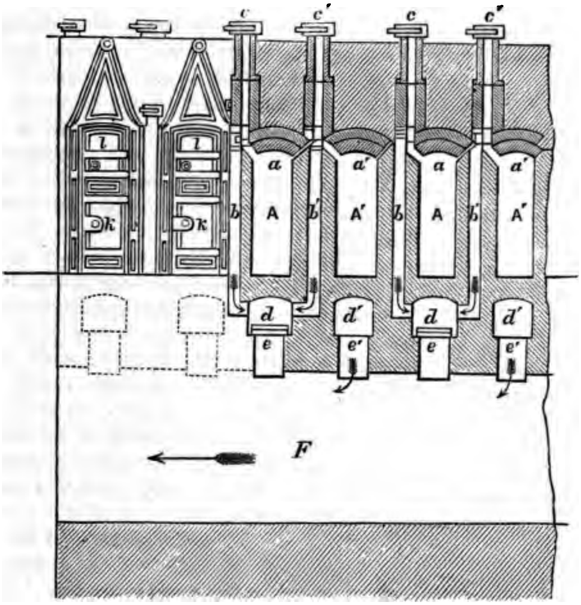

Fig. 14.—Elevation and Transverse Section of the Coppee Coke Ovens.

c, *c*′, contracted towards its lower end, and fitted with damper valves for admitting and controlling the admission of air for the combustion of the volatile vapours and gases from the ovens A,A′ within the flues *b*, *b*′. The flame and products of combustion from the pair of ovens A,A′, after descending through the flues *b*, *b*′, enter through a number of short cross flues, as shown by the arrows, into the horizontal flue *d*, which passes under the bottom of one only of the ovens, A. Here the products evolved from two ovens A,A′ of one pair are therefore mixed, and the more volatile hydrocarbons evolved from the coal at the lower temperature of the oven last charged, are thus raised in temperature by admixture with the more strongly heated products from the other oven, and they are thus the more effectually consumed. The gases then pass from the flue *d* through two cross flues, built at one end of the longitudinal flue *d*, into the corresponding flue *d*′ under the bottom of the second chamber A′ of this pair of ovens. The gases traverse the flue *d*′ in the opposite direction to that which they pursued through *d*, and finally the products enter through two short vertical flues *e*′ into the main flue F, which serves to carry off the gases from the whole of the ovens in the block to a chimney at one end of the same. Flues *e* corresponding to the flue *e*′ just described, but under the ovens A of each pair, are kept closed by fire-clay tiles, except when one of the ovens is under repairs, etc. The passage of the gases from the ovens to the main flue F is controlled by movable tiles, which act the part of dampers or valves.

In the Coppee ovens a large surface of ground coal is thus exposed to a high temperature in a system of retorts or chambers, each heated from its outer surface by the circulation around the sides and beneath the bottoms of the retorts, of the flame and gases produced by the combustion of the volatile products of the distillation of the coal itself. Each pair of ovens is principally heated by the combustion of the volatile products produced from the coal that is being coked in the same pair. The heat in these ovens can be got up rapidly, the coal is pretty uniformly heated throughout, and the coking operation, producing about two tons of coke per oven, is completed in each oven in about 24 hours.

At Ebbw Vale, where these ovens have been erected, the combustion is carried on as above described, by the admission of air to the flues *b* only, but the Coppee Coke Oven Company in their specifications propose to admit also a regulated small proportion of air into the top of the retorts themselves, so that the combustion would be then partially effected within the retorts and partially in the external flues.

For the better preservation of the ovens, cooling flues pass beneath the horizontal flues *d*, *d'*, and through these a current of cold air is drawn by a separate stack at the end of the range of ovens. The top of the ovens is also covered (to prevent too much loss of heat by radiation) with a thickness of about 18 inches of clay, upon which bricks are then laid.

66. **Waste Gases of Coke Ovens.**—These gases consist of carbonic anhydride (CO_2), carbonic oxide (CO), marsh gas (CH_4), hydrogen (H), and nitrogen; the proportions of which vary at different periods of the coking process, but the nitrogen averages about 80 per cent. of the total volume of the gases, carbonic anhydride from 10 per cent. to 12 per cent., carbonic oxide from 2 to 5 per cent., hydrogen from 1 per cent. to 6 per cent., and marsh gas about 1 per cent.; the proportions of hydrogen, carbonic oxide, and marsh gas, appear to decrease towards the end of the operation, while the nitrogen increases in quantity during the same period. The evolved gases, etc., are often utilised in the generation of steam, by passing them for combustion under the boilers. In other arrangements, as in the Simon-Carvès, the Coppee, the Appolt, and other coke ovens, arranged in a similar manner, the gases are burnt to heat the ovens themselves before passing to the boilers.

67. **Coking of Non-Caking Coals.**—The process of making coke from non-caking coal slack, by first mixing it with coal-tar, pitch, etc., has been patented on several occasions. The coal (non-caking, as anthracite, etc.) is broken into small pieces, washed and mixed with one-fourth of its weight of coal-tar or pitch, and then converted into coke either in piles or ovens.

Coke may be obtained from non-caking coals rich in oxygen by heating them rapidly to a high temperature, but on the large scale no economical method of getting up the temperature with sufficient rapidity has been devised. A good coke may be obtained by coking a mixture of non-caking coal slack and caking coals together. Attempts have been made to coke non-caking coals by mixing 1 ton of pitch with 4 tons of coal and then coking, but the coking operation is irritating to the eyes of the workmen.

68. Patent Fuels.—Numerous patents have been taken out for the utilization of coal slack and coaly matters of various kinds; in one process the small coal is tipped into a chamber or kind of funnel, from whence it passes to a disintegrator or mill, from which it is received by an elevator and passed to a hopper and onwards to a pug mill, where it is mixed with a mucilage consisting of 8 lbs. of farina to 1 lb. of carbolic acid; the mixture being then coked in ovens. In another and more recent patent the coaly matter is mixed with about 5 per cent. of clay, the mixture is pressed into large bricks, these placed to saturate in a solution of resin in benzin, and after withdrawal require only to be dried. Recent experiments have been made to utilize peat by mixing it in a state of powder with small coal and sawdust, and then pressing the mixture into blocks.

A Belgian patent fuel, the Anzin, is composed of about 91 per cent. of coal-slack, with 9 per cent. of pitch. Such a fuel yields about 7 per cent. of ash and 1 per cent. of moisture, whilst its heating power is reported to be equal to that of ordinary coal.

69. Sulphur in Coke.—For those operations in which the fuel (coke) is burned while in contact with the metal, as in the cupola for melting iron, etc., it is often necessary that the coke be as free as possible from *sulphur*. If the coal, previous to coking, contains iron pyrites (FeS_2), as is frequently the case, the effect of the coking operation will be to reduce this compound to the protosulphide of iron (FeS), which will remain in the coke unless removed by some further treatment. For this purpose, before drawing the coke from coke ovens, or immediately after drawing, and while the coke is still red hot, it is a usual practice to throw a considerable quantity of water upon the mass; when with sulphurous coke, the odour of sulphuretted hydrogen (SH_2) will be immediately observed, the sulphide of iron in contact with vapour of water suffering decomposition at a red heat, in this manner a partial removal of the sulphur from the coke is effected; in other cases the bottom of the oven has been formed of open bars, to admit of the introduction of superheated steam during the coking, with the view of removing the sulphur; but obviously this can only very partially succeed, except with exceedingly porous coke or charcoal, which will allow of their free permeation by the steam, also if an excess of steam be introduced it gives rise to a loss of carbon, the steam at this temperature being decomposed by the coke. The use of common salt ($NaCl$) has been patented for the *desulphurization* of coke, in which process the coal for coking is mixed with common salt, when on coking the sulphide of iron (FeS) is decomposed with the conversion of the iron into chloride, which, in contact with vapour of water at a high temperature, is resolved into hydrochloric acid and oxide of iron.

70. Calorific Power of Fuel.—The calorific power of a body is an expression indicating the number of parts, by weight of water, which can be raised through one thermometric degree by the combustion of one part, by weight, of the substance. The unit of weight employed is immaterial, it may be a grain, gramme, pound, or a ton; but in order that the figures for different substances may be compared with each other, it is necessary that the water be always raised from the same temperature, since the amount of heat required to raise 1 lb. of water from 0°C. to 1°C. is not the same as is required to raise the same weight from 100°C. to 101°C. For the comparison of the calorific heats of fuels, the amount of water which *one* part by weight of *carbon*, in the form of purified wood charcoal, in burning to the state of *carbonic anhydride*, can raise through 1°C.—viz., from 0°C. to 1°C., is taken as the standard of comparison, and this is found by direct experiment to be 8080 units, *i.e.*, one part by weight of carbon in burning to its highest state of oxidation, viz., *carbonic anhydride* generates an amount of heat sufficient to raise 8080 parts of water from 0°C. to 1°C. In like manner, one part by weight of hydrogen on its combustion with oxygen to form water, generates heat sufficient to raise 34,462 parts by weight of water from 0°C. to 1°C. 8080 and 34,462 are then the *calorific powers* of carbon and hydrogen respectively, from which it appears that *hydrogen* has a calorific power 4·265 times as great as *carbon.*[*]

Berthier estimated the calorific power of a fuel by heating it with protoxide of lead in a crucible from which he excluded the atmosphere carefully, when, the reduction being completed, the weight of the resulting button of lead enabled him to determine the amount of oxygen which had been consumed by the fuel in its combustion; then assuming that the calorific powers of bodies were proportional to the amounts of oxygen required for their combustion, he was enabled to obtain a comparison between the different fuels. The latter supposition, as exemplified in the case below, of carbon burning to the state of carbonic anhydride and carbonic oxide respectively, has been shown not to hold, and accordingly the method is not reliable.

The *calorific power* of *carbonic oxide* (CO) when burnt to *carbonic anhydride* (CO_2), as determined by Favre and Silberman is 2403 units; the amount of *carbon* in carbonic oxide $= \frac{12}{28} = \frac{3}{7}$ of its weight, hence to supply 1 lb. of carbon will require $\frac{7}{3}$ lbs. of carbonic oxide, and therefore $\frac{7}{3} \times 2403 = 5607$ units will represent the amount of heat generated by the combustion of a quantity of carbonic oxide containing the unit of weight of carbon. But one part or unit of carbon in burning to *carbonic anhydride* generates 8080 units of heat, hence in burning to the state of carbonic oxide, it generates only $8080 - 5607 = 2473$ units of heat; that is, the calorific power of carbon, when burned only to *carbonic oxide*, is *less* than one-third of what it is when burned to its maximum state of oxidation, *carbonic anhydride.*

The *calorific power* of a compound, as determined by experiment, is in general *less* than the sum of the calorific powers of its elements, with the *exception* of *olefiant* gas

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[*] If the increment of temperature be taken as 1°F., *i.e.*, from 32°F. to 33°F. instead of from 0°C. to 1°C., then the numbers representing the calorific powers require to be increased in the proportion of 9 to 5, or the calorific powers of carbon and hydrogen become 14,544 and 62,031·6 respectively.

(C_2H_4), which gives the same figure both by calculation and experiment: all other hydrocarbons follow the general rule. The calorific power of marsh gas (CH_4) is found by experiment to be 13,063, as against 14,675·5 calculated from its composition.

The calorific power of a fuel depends upon the amount of *combustible* carbon and hydrogen which it yields. In the calculation of the heat-giving quality of a fuel containing carbon, hydrogen, and oxygen, the latter element is usually considered to exist in combination with an amount of hydrogen sufficient to convert it into water, and therefore it is only the *excess of carbon* and *hydrogen* after this deduction that is available for the generation of heat on the combustion of the fuel. Thus, to calculate the calorific power of dry wood, the average ultimate analysis of which gives approximately—

Carbon . . = 50
Hydrogen . . = 6
Oxygen . . = 41
Nitrogen and Ash = 3
100

Each equivalent of oxygen requires $\frac{1}{8}$th of its weight of hydrogen for conversion into water, hence the 41 of oxygen will require $\frac{41}{8} = 5{\cdot}01$ of hydrogen for its conversion into water, which amount is therefore lost for the generation of heat, and the amount of hydrogen available for the production of heat is only $6 - 5 = 1$ per cent.

Hence on burning 100 parts of this dry wood the

Carbon would generate . . $50 \times 8080 = 404000$ units of Ht.
Hydrogen in excess would generate $1 \times 34000 = 34000$ units of Ht.
Total, $= 438000$ units of Ht.

From this sum requires to be deducted the amount of heat rendered latent by the water supposed to pre-exist in the wood, owing to its containing oxygen $= 41 + 5 = 46$ per cent. of the wood, as also of the amount generated by the combustion of the one part of hydrogen existing in excess, and equivalent to $1 + 8 = 9$ per cent., or altogether there are 55 parts of water per 100 of the fuel to be heated at the expense of the heat of combustion; the latent heat of water is 537°C., therefore the heat rendered latent by the water $= 55 \times 537 = 29{,}500$ units of heat, thus the available heat, excluding the nitrogen and ash, in 100 parts of the fuel $= 438{,}000 - 29{,}500 = 408{,}500$ units; hence the calorific power or heat evolved on the perfect combustion of one part by weight of this fuel is 4085 units. If the fuel be not thoroughly dessicated, but contains a sensible amount of hygroscopic water, then in addition to the latent heat of the water calculated as above, it will be necessary to deduct the heat rendered latent by this hygroscopic water.

From these calculations it is obvious that the *greater* the amount of *oxygen* contained in a fuel, the *smaller* will be its *calorific power*, since its presence not only directly reduces the actual percentage of carbon and hydrogen present in the fuel, but also renders a proportion of these heat-giving elements unavailable for the generation of heat.

Although the statements of the preceding paragraphs, upon the calculation of the calorific power of a fuel, approximate very closely in most instances to the actual results obtained by experiment, yet the formulæ do not completely accord with theoretical considerations, inasmuch as it will be observed that no cognisance is taken of the energy (representing heat) absorbed or developed, as the case may be, during the decomposition of the compounds of carbon, hydrogen and oxygen constituting the proximate constituents of the fuel, either previous to, or at the moment of the combustion of these compounds; neither is any note taken of the work expended in the conversion of the water from the solid state, in which it is presumed to exist in the fuel, into the gaseous state; nor yet of the work of evaporation.

The following, as determined by experiment, are the calorific powers of the bodies mentioned, in centigrade units or calories:—

Carbon, in burning to carbonic anhydride, develops 8080 calories, or units of heat.

Carbon, in burning to carbonic oxide, develops 2473 calories, or units of heat.

Carbonic oxide (CO), in burning to carbonic anhydride (CO_2), develops 2403 calories, or units of heat.

Hydrogen, in burning to water (OH_2), develops 34,462 calories, or units of heat.

Marsh gas **(CH_4), in burning to carbonic anhydride (CO_2) and water (OH_2), develops 13,063 calories, or units of heat.**

Phosphorus**, in burning to phosphoric anhydride (P_2O_5), develops 5747 calories, or units of heat.**

71. Calorific Intensity.—The *calorific intensity, thermal effect,* or *actual temperature* of the products of combustion, does not depend entirely upon the amount of fuel consumed, or the *calorific power* of the fuel, but involves the consideration of the weight and nature of the products of combustion, as also of the rapidity and facility with which the fuel burns; thus in the blast furnace the products of combustion are the same whether *hot* or *cold* blast is employed, but the *calorific intensity* is *much greater* in the hot blast from the more rapid combustion effected. The heat generated in combustion being in every instance first communicated to the products of combustion, usually gaseous, it is evident that as the specific heats of gases and vapours differ, so the temperature of these products will vary with their composition. Thus, if pure carbon be burned in oxygen, of which it requires for its combustion 2·67 times its own weight, the product is 3·67 times its weight of carbonic anhydride, and the heat of combustion is used for raising the temperature of this gas. Now one part by weight of carbon on perfect combustion generates heat sufficient to raise 8080 times its weight of water from 0°C. to 1°C., or 3·67 times its weight to $\frac{8080}{3 \cdot 67} = 2201 \cdot 63°C$. Hence if the capacity for heat of carbonic anhydride and water were the same, the product of combustion should have a temperature of 2201·63°C. at the moment of its production; but taking the specific heat of water at unity, then carbonic anhydride has a specific heat of ·2164, hence the temperature of the 3·67 parts by weight of carbonic anhydride generated by the combustion in oxygen of one part by weight of carbon would have theoretically at the moment of its production a temperature of $\frac{2201 \cdot 63}{\cdot 2164} =$ 10173·6°C., thus the maximum theoretical temperature or *calorific intensity* of carbon $= \frac{8080}{3 \cdot 67 \times \cdot 2164} = 10173 \cdot 6°C.$

If, as in the case of hydrogen, the product of combustion be a *condensible* vapour, it is necessary to deduct from the calorific power of the combustible elements the amount of heat rendered latent by the vapour, or necessary to retain the product in the vaporous form, and in the combustion of hydrogen an allowance requires also to be made for the difference between the specific heat of water ($=1$) and that of steam ($=0{\cdot}4805$), between 0°C. and 100°C., since the initial temperature has throughout been considered as 1°C., and therefore at 100°C. a deduction of $(1-0{\cdot}4805)100=51{\cdot}95$ thermal units requires to be made for each unit of water, as in the following example of the combustion of hydrogen in oxygen :—

Heat Units.

Total heat of combustion of a unit of hydrogen $=$ 34462

Heat rendered latent by the water vapour produced on its combustion $=9\times537=4833$

Specific heat of water vapour $=0{\cdot}4805$

Deduction for difference in specific heat of water and steam from 0°C. to 100°C.

$$=\{(1-0{\cdot}4805)100\}9=467{\cdot}55$$

$$\therefore \textit{Calorific intensity} \text{ in case of hydrogen} = \frac{34462-(4833+467{\cdot}55)}{9\times0{\cdot}4805}$$

$$=6743{\cdot}5^\circ\text{C.}$$

Thus, although the *calorific powers* of carbon and hydrogen are respectively 8080 and 34,462, the *calorific intensities* are 10,173·6°C. and 6743·5°C. respectively, showing that though hydrogen has much the higher *calorific power*, that its *calorific intensity* is much below that of carbon, and thus where intense local heat is required, a fuel containing a large proportion of carbon with a small amount of hydrogen is preferable.

If the fuel be consumed in a mixture of oxygen and nitrogen, as in atmospheric air, then if

T = increase of temperature produced by combustion.
C = amount of carbon in one part by weight of the fuel.
H = amount of hydrogen available for the generation of heat in one part by weight of the fuel.
$3{\cdot}67\,C$ will be amount of carbonic anhydride produced by the combustion of the carbon.
$9\,H$ = the amount of water produced by the combustion of the hydrogen.
l = latent heat of water $=537$.
s, s', s'' = specific heats of carbonic anhydride, water vapour, and nitrogen.
N = quantity of nitrogen in the amount of air containing the necessary oxygen for combination with one part by weight of the fuel, so as to yield carbonic anhydride and water.

d = difference between the specific heat of water and steam from 0°C. to 100°C. = $(1 - 0{\cdot}4805)100 = 51{\cdot}95$ thermal units.

$$\text{then } T = \frac{8080C + 34462H - 9H(l + d)}{3{\cdot}67Cs + 9Hs' + Ns''}$$

If any solid *inert* body, as ashes, etc., be present in the fuel, its amount, multiplied by its specific heat, should be added to the denominator of this last equation.

These calculations of the theoretical calorific power, and of the calorific intensity of fuels, are made, for the sake of simplicity, upon the assumption that the *pressure of the gases is kept constant*, that is, that the gases and products of combustion are free to expand under the ordinary atmospheric pressure of 760 m.m. of mercury.

In all cases the thermal effects above indicated are considerably in excess of those produced in our furnaces, since a very considerable excess of air is always introduced, and the heat of the fuel is accordingly distributed over a much greater weight of gas than is required for the perfect combustion of the fuel, with a consequent cooling effect. Other sources of loss in calorific intensity are due to the presence of inorganic matter or ash in the fuel, to loss from radiation and conduction by the material of the furnace, and lastly, from imperfect combustion, due to the burning of coals in thick layers, or with an insufficient supply of air at the proper periods, when a large amount of carbon is only oxidized to the state of carbonic oxide with the corresponding loss of heat previously indicated.

Further, the high calorific intensities just indicated are not practically attainable, owing to the dissociation (see p. 18) of the gases, which takes place at temperatures considerably below those just quoted as the theoretical calorific intensities of carbon and hydrogen respectively. The temperature of dissociation accordingly furnishes one limit to the heat attainable in metallurgical operations under the most favourable furnace conditions.

72. Selection of Fuel.—The quality of a fuel, as an economical source of heat, cannot be determined entirely from the chemical analysis and the theoretical computation of its calorific power as based thereon, since much of its value will depend upon the manner in which it burns; whether it boils, swells up, and agglutinates together to an excessive degree, preventing thereby the free passage of air through the burning mass, and necessitating therefore continued stirring with its attendant loss; or whether the fuel lies loosely on the bars during combustion without an undue amount of this pasty cohesion, allowing the air to permeate it freely, and thus to consume the coal more completely. To the former class belong the soft bituminous coals, which contain but little ash, while to the latter class belong some of the harder and poorer coals, which thus, from their manner of combustion, compensate for their deficiency in carbon and hydrogen as compared with the former.

Liquid fuels, like petroleum, etc., consist almost entirely of carbon and hydrogen, whilst the fatty oils, methylated and other spirits, contain carbon, hydrogen, and oxygen, and although some of these are applicable as fuel for boiler purposes, yet none of them are as yet of avail for metallurgical operations.

73. Economy in Fuel.—A considerable economy in the item of fuel for certain operations, as in *puddling* and *reheating* furnaces, has resulted from the use of gaseous fuel and the introduction of *regenerative gas-furnaces* under various forms. These appliances utilize the poorest classes of fuel, as coal slack, coke dust, peat, or lignite. The use of revolving puddling furnaces, as those of Danks and others, are also attended with an economy in fuel. The consideration of these furnaces will be found under the subject of "Iron."

By the introduction of the "Bessemer Process" for the manufacture of steel, a saving in fuel has been effected estimated at a million tons of coal annually.

74. Gaseous Fuel.—The use of gaseous fuel for many metallurgical operations has been attended with results of the highest value, for not only is there a saving effected by its use in the weight of coal consumed and the price per ton of the fuel used, but also in the iron industry its use is attended by an improvement in the quality and yield of the iron or steel; and even where the desideratum has been the production of the highest temperatures the advantages have been most marked. For the latter purpose the air, and very generally both the gas and air before they are brought together in the combustion chamber of the furnace, are first heated by passing them through heated flues, or through chambers filled with a chequer-work of fire-bricks, such as is afforded by the Siemens' (p. 174), the Ponsard (p. 199), or other form of regenerator to be subsequently described. The use of gaseous fuel puts the heating operations more under control; and for reheating purposes more regular and uniform heats, with less waste of metal, are the results of its use.

The gaseous fuel employed in metallurgical operations is usually produced either by the distillation of inferior classes of coal, coal-slack, peat, sawdust, etc., or by the incomplete combustion of these substances. The last-mentioned process, carried on under special conditions, such as prevail in the Siemens', the Wilson, and other gas-producing apparatus, yield a producer or generator gas, in which carbonic oxide (CO) is the principal combustible gas; whilst the first-mentioned, or method of destructive distillation, yields the gas used for lighting and certain heating purposes, and depends for its heating qualities principally upon the presence of various hydrocarbons and of free hydrogen in the gas.

75. Producer Gases.—The combustible gases arising from the producer consist of *various hydrocarbons*, the products of the distillation of the coal in the upper portion of the producer; with *carbonic oxide*, resulting from the reduction by carbon of the carbonic anhydride, which is the first product of the combustion of the fuel at the fire-bars. Each volume of carbonic anhydride, in ascending through the producer, passes over the heated mass of coke or carbonaceous matters formed in the upper parts of the producer, and there combines with a further proportion of carbon, yielding thereby two volumes of carbonic oxide, thus $CO_2 + C = 2CO$. *Hydrogen* is also a constituent of the producer gases. It results from the decomposition of the water introduced in small quantities into the ash-pit of the producer, the steam from which rises, and in passing over the incandescent fuel yields, as just stated, carbonic oxide and hydrogen, thus $OH_2 + C = CO + 2H$.

Of the combustible gases just mentioned, carbonic oxide forms about 25 per cent., hydrogen about 12 per cent., and marsh gas CH_4, about 2 per cent. of the gases produced in the Siemens', Wilson, or other gas-producers. Combustible gases thus, in the aggregate, form about 40 per cent. of the gases which escape from the producer, the remaining 60 per cent. being principally nitrogen, with about 4 per cent. of carbonic anhydride CO_2. The exact proportions of the several gases vary, not only with the quality and nature of the fuel, but also with the management of the producer itself; thus, by a proper adjustment of blast, the producer works hotter, and the proportion of hydrocarbons in the producer gases is diminished, while the proportion of carbonic oxide is increased.

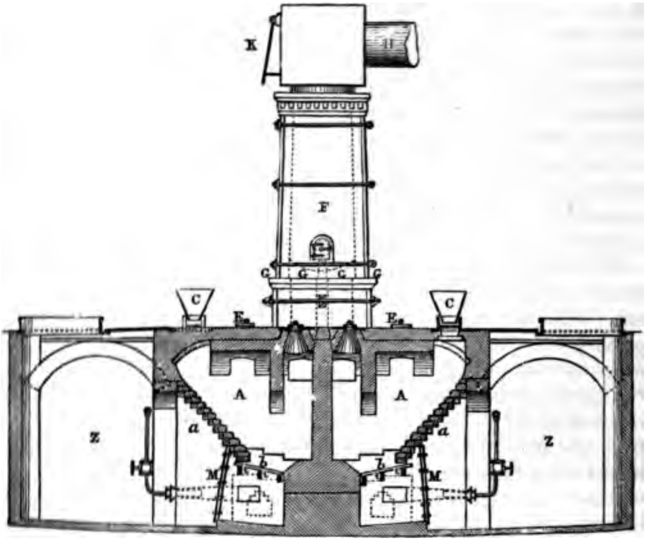

Fig. 15.—TRANSVERSE VERTICAL SECTION OF A PAIR OF SIEMENS' GAS-PRODUCERS.

76. Siemens' Producers.—The *Siemens' Gas-producers* are chambers of fire-brick A, in which the two sides and back walls are approximately vertical, whilst the front side *a* is inclined at an angle of about 50°, and at the foot of this slope is the grate *b* of fire-bars, which slope from the front to the back, and rest upon suitable bearers *t*, *t*. The fuel is supplied from the hopper *c* through an opening in the arched roof of the producer. The hopper is kept well charged with fuel, which is admitted as required into the chamber of the producer by the withdrawal of a slide in the bottom of the hopper. The charging or feeding is thus effected without opening the chamber to the atmosphere during the charging period. Small openings E, closed by a cast-iron ball or plug, permit of an inspection of the interior, and of the insertion of a bar to distribute the fuel as required. In the centre of each block of four producers is built an uptake F, divided up to the level of the dampers G, G, by partition walls into four flues, one of which communicates with each producer; but above the dampers G the uptake forms one common passage. From the top of each uptake is a wrought-iron cross-tube H connected with the main gas tube, or, as it was formerly called, the *cooling tube*, and which thus connects the whole of the producers of a range. There are four dampers G, G, in the uptake F, which can be inserted as required to close the communication between any single chamber and the uptake, as this becomes necessary for repairs, cleansing, etc., without necessitating the stoppage for these purposes of the whole range of producers. At the free end of each cross-tube H it is usual to hang a door K, in the manner shown, and which thus acts as a safety valve, flying outwards (if from the admission of air), any slight explosion arises within the gas tube, but closes immediately afterwards in virtue of its own weight. A little water is often introduced into the producer ash-pit below the bars, which is evaporated by the heat from above, and the steam thus produced ascends, and, besides cooling the bars, it is decomposed on its passage through the mass of incandescent fuel in the producer, and yields thereby carbonic oxide and hydrogen, which thus go to swell the volume of combustible gases from the producer, in the manner indicated in the last paragraph.

It is now a general practice to introduce some sort of steam or air-blast, either from the sides, front, or bottom of the producer, into the body of fuel upon the grate; or else to introduce the blast into the ash-pit of the producer, which is closed for this purpose by fixing iron doors M, M to the same. The *effect of the blast* is, as before mentioned—1. To increase the volume of the combustible gases carbonic oxide and hydrogen; 2. to render poorer and cheaper fuels available for consumption in the producer; 3. to increase the pressure of the gas within the tubes and culverts; and 4. to diminish the number of chambers required to produce the necessary gas for carrying on a given work.

The producers are generally built in rows, with a cave or passage Z, along each side, into which the ash-pits open, and from which the workman clears the bars of clinker, and removes the same along with the ashes.

The producers maintain a pressure of gas within the pipes and culverts, sufficient to prevent the passage of any air into them through crevices in the brickwork, which admission would be attended either with an explosion or a waste of gas, by its combustion within the culverts.

77. Wilson Producer.—The producer of Messrs. Brook & Wilson consists of a cylindrical casing of wrought-iron plates, usually of from 8 feet to 10 feet in diameter, and from 10 feet to 12 feet 6 inches in height, and which is lined with brickwork. The producer has a solid brick bottom, and is without grate-bars, so that it forms a closed chamber, except for the two doors G, G, which are used for clearing away the clinker and ashes from the hearth. The sight-holes *h*, *h* are for observing the state of the working of the apparatus, and for the occasional introduction of bars for breaking down the fire. The charging hole is in the roof of the producer, and over it stands the hopper A, closed by the cone as shown. The hopper A is kept filled with fuel, and can be closed by a plate on its top side whenever it is necessary to drop the fuel into the producer, thus preventing the access of air at all times to the interior of the producer. In the centre of the chamber and across the hearth is a tee-shaped blast-distributor T, which is carried sufficiently high into the body of the producer as to always deliver the blast above the mass of clinker and ashes, which collect on the bottom in the intervals between the cleanings out, which clearing is effected once in the course of the 24 hours. The blast distributor is connected with the blowing apparatus Z, consisting of an annular steam jet, which blows into the top of a vertical conical bell-mouthed tube or nozzle, whereby the steam draws along with it a strong blast of atmospheric air. The apparatus is proportioned so that a mixture of about 5 parts of steam to 100 parts of atmospheric air is forced into the producer for the maintenance of combustion within the same. The gases pass out from the producer by the ports or openings *d*, *d* into the annulus E, from which the iron tube or downtake D carries them to the brick culvert or gas-main, by which they are conveyed to the furnaces. In the downtake D is a valve V, which serves to shut off the producer, either for repairs, etc., as may be required, or for the clearing out of clinker and ashes. The last-mentioned operation is of about an hour's duration, and during this time the blast is turned off; the valve V is closed, and the stopper holes L, L are opened to allow of the escape of any gas. The door M is then opened, and iron bars are inserted across the producer, so as to act as temporary fire-bars to carry the superincumbent fuel whilst the clinker and ashes are being withdrawn through the doors G, G.

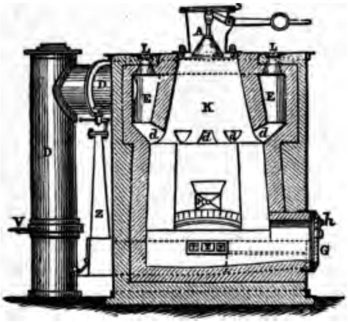

Fig. 16.—Vertical Section of the Wilson Gas-Producer.

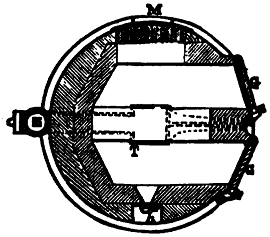

Fig. 17.—Transverse Section of the Wilson Gas-Producer.

The action of this producer in producing gas is the same as that already described (p. 61). A small proportion of volatile hydrocarbons from the fuel in the upper zones of the producer escapes into the gas culvert, whilst the carbon of the fuel first burns to carbonic anhydride as the blast enters, but the latter gas becomes reduced to carbonic oxide as it ascends through the superincumbent incandescent fuel. The steam which also passes in with the blast is decomposed by the heated carbon, with the production of carbonic oxide and hydrogen. The producer is usually kept a little more than half filled with fuel, but whenever the fuel stands in the part K, above the ports *d. d.*, then a partial distillation of the coal by the heat from below follows, and the hydrocarbons, tar, etc., so evolved have to pass downwards to the ports *d. d.* before escaping. In this manner the tar separated in the upper zone passes into the hotter regions of the producer where it is burnt or consumed, and cannot therefore be subsequently deposited in the tubes from the producer. The only deposit in the tubes from these producers is a little sooty deposit, which is easily burnt out at intervals.

78. Casson's Producer.—This producer, as applied to the Casson-Bicheroux furnace (page 200), is essentially a Siemens' producer, provided with an arrangement for heating the air required for the combustion of the gases upon the furnace hearth. Such a producer is, therefore, especially applicable to the Bicheroux and other furnaces where moderately high temperatures are required without the use of regenerators, and where a separate producer is usually attached to each furnace. For reheating purposes the producer may, however, be placed at any convenient distance behind the furnace.

The general arrangements of this producer are the same as those of the Siemens' producer already described; but in the base of the Casson producer there are also fixed cast-iron boxes into which atmospheric air is first admitted, before it passes on into the iron or clay pipes built in the back of the producer. After circulating through these boxes and pipes, the air leaves for the fire-bridge of the furnace by two flues, built one along each side of, and parallel with, the gas-flue from the producer to the furnace. Combustion ensues at the fire-bridge of the furnace, where the heated air meets the gases from the producer. It is often advisable with this producer to apply a forced blast both to the producer itself, and also for driving the air through the heating arrangements and so to the furnace, the chimney draughts often proving insufficient to draw the necessary air through the arrangement.

CHAPTER IV.

IRON.

METALLIC IRON in a state of purity is comparatively little known, and void of commercial importance; but its combinations with *carbon*, modified by the presence of other elements, constituting it *malleable iron*, *steel*, and *cast* or *pig-iron*, are of very considerable practical utility; the consideration of the composition and properties of these varieties will be treated of in future chapters, the present one being confined to the consideration of the pure metal and the points of metallurgical interest in the compounds formed by its combinations with the other elements, metallic and non-metallic.

Pure iron, which is only prepared as a chemical curiosity, may be obtained by heating pure ferric oxide (Fe_2O_3) in a current of hydrogen gas; by heating to whiteness in a closed crucible a mixture of iron wire or iron-filings with magnetic oxide of iron covered with a layer of glass, or by the electrolytic decomposition of a solution of ferrous chloride. As obtained by the first method, employing only a dull red heat, the metal forms a dark grey powder, which takes fire in the atmosphere if slightly heated; reduced at a higher temperature the metal is almost silver white, capable of receiving a high polish, and is no longer pyrophoric. Pure iron is softer than ordinary malleable iron, and its malleability is unaffected by heating to redness and then suddenly cooling, neither it hardened by this treatment. It is very tenacious and ductile, has a scaly or crystalline fracture, is scarcely acted upon by sulphuric or hydrochloric acids at the ordinary temperature, but if heat be applied it is dissolved with the evolution of hydrogen. Its magnetic power is very high, but it does not retain its magnetism; its specific heat is ·113795, and the specific gravity of electro-deposited iron is 7·875, which, after rolling, becomes somewhat less. If wrought-iron be melted and then allowed to cool, it always presents a crystalline fracture, exhibiting faces of the cube; if rolled or hammered out, however, a fibrous structure is developed. The electrical conductivity of iron is higher the freer it is from impurities. The melting point of pure iron has not been decided with any degree of certainty, but it is fusible at a temperature below the melting point of platinum. The purer the metal, especially its freedom from carbon, and the higher is the temperature required for its fusion. Iron is unaffected by dry air at the ordinary temperature, except when the iron is in a very fine state of division (such as exists when it is reduced at a low heat from ferric oxide by hydrogen), when it takes fire spontaneously; but iron is rapidly oxidized (Rusts, p. 19) under the joint action of air and moisture; and if heated to redness in contact with the atmosphere, the metal oxidizes rapidly. Water deprived of air or free oxygen does not affect iron at the ordinary temperature, but the finely divided metal decomposes it at a temperature below its boiling point. The oxidation of iron by water is further promoted by the presence of carbonic anhydride, water holding carbonic anhydride in solution attacking the metal even in the absence of air or free oxygen. If a perfectly bright clean strip of iron be immersed in cold fuming nitric acid, it assumes the *passive* condition, that is, it may be left during any length of time immersed in the acid without any solution of the metal, whereas ordinary nitric acid attacks the metal vigorously. Iron, as also its combinations with carbon, such as steel and cast-iron, appear to have when in the fused state the power of *occluding* certain gases, which gases are, to a certain extent, liberated as the metal solidifies, thus electro-deposited iron occludes from 17 to 20 times its own volume of hydrogen. The chemical symbol of iron is Fe, and its atomic weight is 56.

79. Iron and Oxygen.—Iron combines with oxygen in several proportions, of which the most important are *ferrous oxide* (FeO), *ferric oxide* (Fe_2O_3), and the combination of these two, constituting *magnetic oxide*. The first named is a very unstable compound obtained, according to Debray, as a black non-magnetic body, when steam and hydrogen in certain proportions are passed over heated ferric oxide. The *hydrated* *oxide* or *ferrous hydrate* is obtained as a white flocculent precipitate when potash or soda is added to a solution of a ferrous salt, the precipitate absorbing oxygen almost immediately, changing thereby to green and then to brown. Ferrous oxide is a powerful base, and enters largely into the composition of the various *slags*, *cinders*, etc., produced in the metallurgical treatment of iron; and by its combination with acids produces an important series of salts known as ferrous, or proto-salts of iron, which decompose on exposure to the atmosphere with the production of basic salts of ferric oxide. Of ferrous salts, the most important to the metallurgist are the carbonate and the sulphate; the former occurs anhydrous and crystallized in *spathic ore* or *siderite* and amorphous, along with clay, lime, etc., in the various clay ironstones. The carbonate suffers decomposition on heating to redness with access of air, carbonic oxide and carbonic anhydride being evolved, while magnetic oxide remains. Ferrous carbonate is slightly soluble in water, but more so in water containing carbonic anhydride. This solution, on exposure to air, is decomposed with the precipitation of ferric oxide (hydrated).

80. Ferrous Sulphate.—Ferrous sulphate or proto-sulphate of iron occurs in commerce in the form of pale green crystals containing seven equivalents of water, which they lose more or less completely on heating, according to the temperature applied; the first application of heat being attended with the melting of the crystals in their water of crystallization, heated further and the salt loses six equivalents of water, when a further increase in the temperature is attended with the production of an anhydrous gritty powder, and if exposed to a still stronger heat the salt suffers decomposition, a bright red pulverulent mass of ferric oxide (Fe_2O_3), called commercially *rouge* or *colcothar*, is obtained, while sulphurous anhydride (SO_2), and anhydrous sulphuric acid are evolved. Ferrous sulphate is formed when a sulphide of iron is exposed for some time to moist air, also when a sulphide is roasted at a low temperature with free access of air.

81. Ferric Oxide.—Ferric oxide (Fe_2O_3), called also *red oxide of iron*, exists in the anhydrous state in the minerals *hæmatite*, *iron glance*, *specular iron*, *micaceous iron ore*, and in the commercial oxide known as *rouge* or colcothar, prepared by heating ferrous sulphate as above, with subsequent levigation, or by heating ferrous sulphate and sodic chloride (NaCl), or by simply heating the nitrate or oxalate of iron. Ferric oxide crystallizes in rhombohedrons; but, as occurring in the mineral *martite*, it crystallizes in cubic forms, has a steel grey colour with a bright lustre, but the powdered substance is always red; the artificial varieties are usually non-magnetic. Ferric oxide is very stable, and is not volatile; but if heated to nearly a white heat it suffers decomposition, liberating oxygen, and leaving a fixed residue of magnetic oxide.

$$3Fe_2O_3 = 2Fe_3O_4 + O$$

Ferric oxide is reduced to the metallic state by heating with *carbon*, *carbonic oxide*, *hydrogen*, *ammonia*, or *cyanogen;* if heated with excess of sulphur, ferrous sulphide is obtained with the evolution of sulphurous anhydride (SO_2). Ferric oxide is soluble in hydrochloric, nitric, and sulphuric acids, producing thereby a class of stable compounds known as ferric salts; but it is only very slowly acted upon by mineral acids if subjected to a previous ignition. This oxide is used as a colouring material for glass and porcelain, to which it imparts a purple red or orange yellow colour, according to its treatment.

Hydrated ferric oxide (Fe_2O_3, $3H_2O$) is precipitated as a bulky reddish brown precipitate, when potash, soda, or ammonia is added to a solution of a ferric salt, in which form it is amorphous, readily soluble in acids, and slightly soluble in water containing carbonic anhydride; if kept under water for a considerable time it loses a portion of its water of composition, and if heated in boiling water during seven or eight days it retains only one equivalent of water, when it assumes the form of a brick-red amorphous powder, but slightly acted upon by hydrochloric, nitric, or sulphuric acid. Hydrated ferric oxide occurs in the minerals and ores of iron known as *brown hæmatite, limonite, and göthite.*

82. Magnetic Oxide.—Magnetic oxide of iron (Fe_3O_4) occurs native as *magnetite*, a black lustrous mineral, having a black streak; it crystallizes in the cubic system, is strongly magnetic in both the native and artificial varieties, is also in native specimens frequently polar. This oxide constitutes the ordinary *iron scale* or *hammer slag*, and is produced when iron is heated to redness in aqueous vapour, when iron is burned in oxygen gas, when ferrous sulphate with chloride of calcium are heated in covered crucibles (Kuhlman), or by the action of heat on ferrous silicate (Ebelmen).

When iron is oxidized by heating it in contact with the atmosphere, two or three distinct layers of scale or slag form on the surface of the iron, which are readily detached, as by bending or hammering the metal, and of which the outer layer is more highly oxidized than the inner, and is slightly redder in tinge from the presence of a variable excess of ferric oxide over that contained in the inner layer. The oxide occurring in the outer layer of *hammer scale* is fusible only at a high temperature, is strongly magnetic, and slightly metallic in lustre; while the inner layers are more porous, dull, and non-metallic in lustre, less brittle, and also less powerfully magnetic.

83. Ferric Acid.—This is the highest oxide of iron, and has never been prepared in a free state; but its combinations with alkalies, as ferrate of potash, may be obtained by fusing finely powdered iron filings with nitre, or in the wet way by passing chlorine through a concentrated solution of potash holding hydrated ferric oxide in suspension, potash being added from time to time to maintain the alkalinity of the solution. Ferrate of potash decomposes spontaneously, and if slightly heated decomposition ensues, even in vacuo, with the precipitation of ferric oxide; it is also decomposed by chlorine in excess, by ammonia, strong acids, and organic matters.

84. Iron and Sulphur.—Iron and sulphur have powerful affinities for each other, uniting directly under the influence of heat in varying proportions; metallic iron heated with an excess of sulphur yielding ferrous sulphide (FeS), ferric sulphide (Fe_2S_3), disulphide of iron (FeS_2), or magnetic sulphide according to the temperature employed, the higher the heat applied, and the lower the degree of sulphurization in the product; several other lower sulphides can also be obtained by special methods. Very small proportions of sulphur in malleable iron or steel suffice to induce in the metal the property of *red shortness* or unworkability at a red heat, though it may be hammered or rolled while in the cold state with facility; while a small proportion, from 0·3 per cent. to 0·5 per cent. of sulphur, in cast-iron may be useful for foundry purposes, as producing a somewhat stronger iron as required for special castings; the peculiar dappled or reticulated appearance presented by the fractured surface of certain Swedish pig-irons is ascribed to the presence of sulphur; the addition of sulphur to grey pig-iron tending to the production of white iron.

Ferrous sulphide has not been found free in nature, but it exists in ores of nickel along with sulphide of nickel, and with sulphide of copper in copper pyrites; it is obtained artificially by the direct action of sulphur upon iron at a red heat, by igniting hammer scale with sulphur, by heating ferrous sulphate to a bright red heat in a crucible lined with charcoal, or by the precipitation of a ferrous salt with an alkaline sulphide. As obtained by the dry methods, it is a dark bronzy or black porous mass, having a semi-metallic lustre, and is not sensibly altered by exposure to the air at ordinary temperatures; but if gently heated it is converted partly into ferrous sulphate, which, at a stronger heat, is again decomposed with the production of ferric oxide and the evolution of sulphurous anhydride (SO_2). Aqueous vapour, passed over this sulphide, converts it into a black slightly magnetic mass, hydrogen and sulphuretted hydrogen SH_2 escaping. Ferrous sulphide heated with carbon is but slightly affected, with ferric oxide a portion of the sulphur is oxidized, but no metallic iron is separated; but if heated with ferrous or ferric sulphate in proper proportions, the sulphur from the whole of the ingredients is entirely eliminated as sulphurous anhydride (SO_2). When litharge (PbO) is fused with $\frac{1}{30}$th of its weight of ferrous sulphide, the sulphur escapes as sulphurous anhydride (SO_2), while metallic lead is separated beneath a layer of the fused oxides of iron and lead. Ferrous sulphide combines readily with other metallic sulphides on the application of heat, as will be exemplified in the metallurgy of copper. Silica is without action on this sulphide when heated with it, but if mixed with carbon, the sulphide is very largely decomposed.

85. Ferrous Disulphide (FeS_2).—This compound occurs abundantly in nature, constituting *yellow iron pyrites, cubic pyrites* or *mundic*, and as *white iron pyrites, marcasite* etc. The first named varieties occur as bronze or brass yellow, opaque solids, having a metallic lustre, and crystallizing in the cubic system, or as radiated, fibrous, or reniform masses. Marcasite or white iron pyrites is lighter in colour, approaching to whiteness, is usually softer than the yellow variety, and crystallizes in the rhombic system; this variety weathers very rapidly, while yellow pyrites in its compact forms does not sensibly alter by exposure to the atmosphere, but if finely divided it oxidizes rapidly with the formation of ferrous sulphate, the oxidation being attended with a rapid rise in the temperature, which, if allowed to rise too high, results in the evolution of sulphurous anhydride (SO_2), while ferric oxide remains. The residue from the combustion of iron pyrites in the manufacture of sulphuric acid is known as "*Blue Billy*," and is employed as an iron ore, and for the fettling of puddling furnaces in the Cleveland district.

86. Magnetic Pyrites, called also **pyrrhotine**, occurs native, often associated with ores of nickel and copper; it is of a colour between bronze yellow and copper red, with a metallic lustre quickly tarnishing, is slightly attracted by the magnet, and is often itself magnetic. This sulphide is obtained as a brownish yellow mass when the disulphide (iron pyrites) is heated to redness in a covered crucible.

87. Iron and Nitrogen.—The evidence concerning the existence of a chemical combination between these elements is exceedingly contradictory; Fremy, Savart, Despretz, and others state that when iron wire is heated for a considerable time in a current of ammonia, that the iron increases in weight with a diminution in its specific gravity, also that the iron so treated is white, brittle, and less alterable by exposure to the air than is the iron previous to this treatment; it is also still magnetic, soluble in acids, and can be hardened by heating and sudden cooling in water. Bois and Boussingault have examined commercial iron and steel for nitrogen, and state that they find from 0·005 per cent. to 0·124 per cent. of nitrogen in all irons.

88. Iron and Phosphorus. — These elements combine readily under the influence of heat, producing grey or whitish fusible compounds. Percy describes and formulates seven compounds of phosphorus and iron, of which the lowest one ($Fe_{12}P$) is formed when phosphorus and red hot iron are brought into contact; while the third in his series, having a constitution represented by Fe_4P, is metallurgically the most important; it is obtained by heating phosphate of iron with charcoal in a smith's fire or other source of intense heat; as thus prepared it is very hard, brittle, capable of receiving a high polish, and is only faintly magnetic.

The presence of only small quantities of phosphorus in malleable iron and steel produces a marked effect in the working qualities of the metal. Karsten states that 0·3 per cent. of phosphorus in malleable iron, while not sensibly affecting its tenacity, increases its hardness; that with 0·5 per cent. the metal begins to show signs of deterioration, its tenacity manifestly diminishes, and it is sensibly *cold short*, that is, cannot be worked under the hammer in the cold state without cracking or breaking, though when heated it may be rolled or hammered easily; with 0·75 per cent. of phosphorus the decrease in tenacity and cold shortness of the metal are very decided, while the presence of 1 per cent. renders wrought-iron exceedingly brittle and unusable, except for special purposes. Phosphorus increases the hardness and fluidity of pig-iron, and it is generally considered to render pig-iron more largely crystalline on fracture; its average quantity in foundry iron is about 1 per cent.

The presence of a notable quantity of phosphorus in iron ores is especially objectionable, since this element passes almost wholly into the pig-iron smelted therefrom, unless the reduction be imperfect, and a highly basic slag containing iron with a portion of the phosphorus in the state of phosphoric anhydride be allowed to form.

89. **Iron and Arsenic.**—These elements readily unite, producing a series of compounds or arsenides of iron varying from iron grey to white in colour. The arsenides, brittle and non-magnetic, differ much in fusibility, and if roasted with access of air, a large proportion of their arsenic escapes as a sublimate of arsenious anhydride (As_2O_3), while basic arseniates remain behind. Arsenic, though not a very

general impurity in iron, occurs frequently as ferrous arsenide in the products known as *speise*, produced during the metallurgical treatment of the arsenical ores of nickel, cobalt, gold, silver, and lead. Arsenic, like sulphur, renders malleable iron *red-short*, but in pig metal, for producing chilled shot or other chilled castings, its presence has been stated to be advantageous. In Sweden and elsewhere articles are case-hardened by coating them with a paste of hydrochloric acid, with arsenious anhydride, powdered leather, horn, or other nitrogenous bodies, and then heating the articles so coated to bright redness in a muffle or other suitable furnace.

90. Iron and Silicon.—As already stated, the union of iron and silicon cannot be effected by the simple heating together of silica and iron, but if carbon be also present, and a sufficiently high temperature be employed, then the silicon is reduced. In this manner Riley has succeeded in obtaining a hard, highly crystalline, light grey or silvery white alloy of silicon and iron, containing 21 per cent. of silicon. This alloy is so brittle that it may be powdered in a mortar. Silicon can be partially separated from pig-iron by fusion with ferric oxide (Fe_2O_3) and manganese, when a manganous silicate is produced.

Silicon is reduced in the blast furnace in larger proportion, as the temperature of the furnace is increased; as by the use of hot blast, etc. The silicon so reduced enters in considerable proportion into the pig-iron produced; and since an increase in the temperature of the furnace is a condition required for the production of grey pig-iron, as well as for the reduction of silicon, hence grey pig-iron is usually more highly silicious than white iron; the further consideration of the effect of silicon and of its amount in pig-iron is treated of subsequently. Silicon occurs usually only in small quantity in malleable iron and steel, to which, when present, it imparts hardness and brittleness, but with a loss of tenacity.

The slags, cinders, etc., produced in the blast, puddling, refining, reheating, and other furnaces employed in the metallurgical manipulation of iron, are essentially oxidized products of silicon and iron, consisting for the most part of a ferrous silicate (silicate of protoxide of iron), containing about 30 per cent. of silica with 70 per cent. of ferrous oxide, the latter replaced more or less by other bases, as manganous oxide, etc.; on heating these slags or cinders with carbon, as by smelting in the blast furnace, Percy states that about two-thirds, or two out of the three equivalents of ferrous oxide present in the slag are reduced, the pig-iron so obtained being known as *cinder-pig*, to distinguish it from the iron smelted from pure *ore* or *mine*. When the tribasic silicate or slag is heated with access of air it is more or less completely converted into sesquioxide with the separation of the silica; thus "bull dog," a very refractory dark grey, lustrous body employed in the lining of puddling furnaces, etc., and obtained by roasting "*tap cinder*" (the slag of the puddling furnace) during several days in kilns, somewhat resembling ordinary coke or brick-kilns, consists largely of a comparatively infusible ferric oxide (Fe_2O_3), with a small amount of silica; during the roasting of the tap cinder two products melt and liquate out, both of which are more silicious than the "bull dog;" the one known as "*bull dog slag*" collects in the bottom of the kiln, while the other, which runs out through openings in the side of the kiln, is highly silicious, and contains the largest proportion of the phosphoric anhydride always present in tap cinder.

91. **Iron and Carbon.**—Upon the degree of carburization of iron, modified by the presence of other elements, as sulphur, phosphorus, silicon, and manganese, largely depends its classification into cast-iron, steel, and malleable iron, with the widely different qualities possessed by these bodies; in the first named the carbon may exist to the extent of about 5 per cent., while in the latter it may be almost entirely absent. Carbon and iron do not combine at ordinary temperatures, but if raised to a temperature *at* or *above* redness, combination between the two ensues with greater or less rapidity; in the process of cementation for the production of steel, the bars of iron are heated to from 1000°C. to 1200°C. in contact with charcoal, when a combination of iron and carbon known as *blister steel* results. At ordinary furnace temperatures iron does not decompose carbonic oxide, but if the temperature be raised still higher, as in the blast furnace, carbonic oxide is decomposed, and a certain amount of its carbon enters into combination with the iron; the *carburiza-*

tion of iron can also be effected by heating it in coal gas, the vapour of paraffine, and other volatile hydrocarbons; or by heating malleable iron to a lower temperature in contact with carbonaceous matters, cyanogen compounds, etc., as in the operation of *case-hardening*. In cast or pig-iron, the carbon exists in all cases both as combined and graphitic carbon; in *grey iron* the carbon exists almost wholly as graphite, which Mr. Snelus has shown can be detached from the crystals of iron, and separated therefrom by the mechanical operation of sifting; but in *white iron*, as *speigeleisen*, the carbon is almost wholly combined or dissolved, only a small quantity existing as graphite; while in *mottled iron* the proportions of combined and graphitic carbon are more nearly in equality. Cast-iron in its fluid state is capable of holding an amount of carbon in solution, which, as the metal cools slowly, separates as graphite or *kish*, while if the metal be suddenly cooled the greater portion of the carbon is retained in combination with the iron.

92. Iron and Copper.—The direct union of iron and copper is attended with difficulty, but an apparently homogeneous alloy can be obtained by the simultaneous reduction of the *oxides* of iron and copper, if the oxide of iron be not in excess. The presence of 0·5 per cent. of *copper* in wrought-iron or steel renders it *red-short*, while 0·3 per cent. yields a steel, which cracks at the edges, and ·0286 per cent. of copper sensibly diminishes the tenacity of malleable iron.

93. Iron and Zinc.—These metals yield, when heated together, a more or less crystalline, brittle, and friable alloy of no practical use; but by immersing malleable iron freed from scale or rust by previous immersion in dilute sulphuric acid, in a bath of molten zinc covered with sal ammoniac (NH_4Cl), a thin coating or alloy of zinc and iron is deposited on the surface of the plate, whereby the iron is preserved from rust and corrosion on exposure to the atmosphere, and such plates, under the name of *galvanized* or *zinced* plates, are of extensive application in the arts.

94. Aich Metal.—This is an alloy consisting of about 60 per cent. of copper, with 38 to 44 per cent. of zinc, and from ·5 per cent. to 3 per cent. of iron. Aich metal can be rolled, hammered, or drawn into wire, it is possessed of very considerable tenacity, and said to resist the action of sea-water. A similar alloy, patented by *Keir*, is formed by melting under a layer of charcoal 100 parts of copper with 10 of iron, and to the bath so formed adding by degrees 75 parts of zinc; and *sterro-metal*, a brass yellow alloy of great elasticity and tensile strength, capable of being worked either hot or cold, and proposed as a material for the construction of ordnance, is a similar alloy, consisting of 60 per cent. of copper, with 34 to 44 per cent. of zinc, 2 to 4 per cent. of iron (malleable iron is used), and from 1 to 2 per cent. of tin.

95. Iron and Tin.—These metals when heated together combine in various proportions, producing alloys varying from grey to white in colour, with a granular or crystalline fracture, more or less brittle, and harder than tin. It has been proposed to harden the tops of rails by the addition of from ·1 per cent. to ·5 per cent. of tin to the puddler's charges when manufacturing iron for this purpose; but its use has not proved successful, the metal so produced being *cold-short*, brittle, difficult to weld, and could only be hammered at a red heat with great care. When a clean surface of sheet-iron is immersed in a bath of molten tin, a firm adherent coating of a highly stanniferous alloy is deposited on the surface, the plate so prepared constituting the ordinary *tin plate*.

96. Iron and Titanium.—The existence of an alloy of iron and titanium has not yet been definitely shown, though by the treatment of titaniferous iron ores in the blast furnace, pig-iron has been obtained, as will be subsequently described, containing upwards of 1 per cent. of *titanium*, either alloyed or disseminated through the iron; but the malleable iron or steel produced therefrom affords no evidence of its presence.

97. Iron and Manganese.—Very little is known of the alloy of pure iron and manganese; but manganese is a common constituent in pig-iron, its tendency, when in considerable proportion, being to render the pig white and more brittle. Mushet states that pig-iron containing 22 per cent. of manganese ceases to be magnetic. The presence of manganese in iron ores promotes the elimination of sulphur from the product obtained on smelting the ore, but does not appear to affect the proportion of the phosphorus.

98. Iron and Tungsten.—Tungsten reduced from tungstic acid in the presence of iron readily alloys with the latter; thus, when grey iron is heated to a very high temperature along with tungstic acid, the graphite of the pig-iron, by combination with the oxygen of the tungstic acid, reduces the tungsten, which, alloying with the iron, produces an exceedingly hard, fine-grained, and almost silver-white steel, which is more or less malleable according to the amount of tungsten present. If *speigeleisen* or *white* iron be substituted for grey iron, no sensible amount of the tungsten is reduced.

99. Iron and Lead.—No alloy of these two metals is satisfactorily known.

100. Iron and Antimony.—An alloy of antimony and iron always results as a *regulus* in the reduction of antimony from its sulphide by treatment with metallic iron in excess. The presence of from ·2 per cent. to ·3 per cent. of *antimony* in malleable iron suffices to render it both *hot* and *cold-short.*

101. Iron and Bismuth may be alloyed by melting together the two metals in certain proportions; but on puddling a bismuthic pig-iron, the bismuth would pass out into the slag.

102. Iron and Nickel.—The alloys of nickel and iron, as formed by the fusion of the two metals, or by the reduction of their mixed oxides, are whiter than iron, are magnetic, capable of receiving a high polish, not so easily affected by air and moisture, and retain the malleability of iron. A natural alloy of iron and nickel occurs in meteoric masses; and nickel, as also cobalt, frequently occurs in minute quantities in malleable iron.

103. Iron and Cobalt.—These metals alloy well together, and the product is similar in character to the last described alloy, but Hassenfratz describes it as being inclined to *red shortness.*

104. Iron and Silver.—Iron and silver do not appear to alloy well together; for although the mixture of the metals appears homogeneous while in the fluid state, after cooling the silver separates throughout the mass. Karsten says that *silver* induces *red shortness* in malleable iron.

105. Iron with Gold and Platinum.—These metals alloy well together, small quantities of iron added to gold increasing its hardness. With platinum and steel an alloy may be obtained which is fusible at a temperature considerably below that required to melt steel; and with 1 per cent. of platinum steel yields a tenacious, ductile, and very fine grained product.

106. Iron and Aluminum.—These metals may be alloyed in all proportions, but the compounds so produced are of no practical value in the arts; aluminum, if present in malleable iron, steel, or cast-iron, occurs only in faint traces, and Karsten concludes that its presence would be to diminish the strength of the iron, a conclusion confirmed by the experiments of the author on alloys of aluminum and steel.

107. Iron and Chromium.—The alloys of iron and chromium are less fusible and less magnetic than iron alone. The addition of from 1 per cent. to 2 per cent. of chromium appears to harden and slightly increase the tenacity and ductility of cast-steel.

CHAPTER V.

IRON ORES.

Of the minerals which occur in greatest abundance, and contain iron in large proportion, are the oxides, disulphide, carbonate, phosphate, titanate, and silicate of iron; but for the extraction of the metal, the oxides and carbonates alone are extensively available, and these, accordingly, will only be noticed here, viz:—

108. Magnetic Iron Ore or Magnetite (Fe_3O_4).—This ore contains in its pure state 72·41 per cent. of iron, constituting it the richest ore available for iron smelting; and it is from this, smelted with charcoal, that is obtained the famed Dannemora iron. Magnetite crystallizes in the cubic system, is of a black colour, and gives, when drawn over a slab of unglazed pottery-ware, or scratched by the knife, a black mark, this test being known in mineralogy as the *streak* of the mineral, which term will be adopted hereafter. It occurs massive with a crystalline or granular fracture, and also in the state of sand; is strongly magnetic, and sometimes polar, by which quality it may be distinguished from chrome iron ore. Magnetic iron ore is very widely distributed, occurring abundantly in Norway, Sweden, Siberia, Canada, and the United States. It is also found in the west of England.

109. Franklinite is very similar to magnetite, but is less magnetic, and gives a dark reddish brown streak; the analyses of this ore by Rammelsberg show it to contain 45·16 per cent. of iron, 9·38 per cent. of manganese, and 20·30 per cent. of zinc, all existing as oxides; it occurs chiefly in the Silurian limestones of New Jersey in America, and several other of the United States, where it is treated for the extraction of zinc, and the residues so obtained smelted for speigeleisen, a highly manganiferous pig-iron.

110. **Red Hæmatite.**—This name is applied generally to minerals consisting essentially of anhydrous ferric oxide (Fe_2O_3); the crystallized varieties, as *specular iron ore or iron glance,* occurring in rhombohedral forms. Hæmatite varies in colour from bluish grey to deep red, but the streak is invariably red; in its pure state it contains 70 per cent. of iron, and, according to its physical characters, it has received various names; thus, the scaly or micaceous varieties, as those of Devon, are known as *micaceous iron ore;* the hard, massive, and reniform masses, having a fibrous or radiating structure, and occurring chiefly in the Cumberland district, are known as *kidney ore;* the more earthy varieties constitute *red ochre;* while the soft, unctuous, compact form constitutes the *puddler's ore* or *puddler's mine,* used for the fettling of puddling furnaces. The most important deposits of this ore in England occur in the permian and carboniferous rocks of Lancashire and Cumberland, where the mineral is classed as "hard" or "soft," according as it contains a large excess of free silica or otherwise; and it is now smelted largely in the vicinity of the mines, the pig-iron produced being highly suitable and much in demand for conversion into steel by the Bessemer process. Varieties of this ore also occur largely in the United States, Canada, Sweden, and Norway.

111. **Brown Hæmatite,** called also **Brown Iron Ore,** is an hydrated ferric oxide ($2Fe_2O_3, 3OH_2$), usually compact or earthy, and of various shades of colour, from blackish to yellowish brown, with a dull lustre, and an invariable yellowish brown streak. *Bog ore* or *limonite, lake ore,* as also *göthite,* belong to this class, the latter a crystallized and very rich variety. Brown hæmatite contains, when pure, 59·89 per cent. of iron, and 14·44 per cent. of combined water, but it frequently contains manganese with more or less earthy impurities; it occurs abundantly in the carboniferous formation of the Forest of Dean, in Glamorganshire, in Devonshire, in Northamptonshire, and Lincolnshire; while in France and Germany it is one of the ores principally smelted. *Bog iron ore* usually contains a notable quantity of phosphorus, rendering the irons produced therefrom only applicable to foundry purposes; it is smelted largely in Canada; and the so-called *lake ores* are smelted in Sweden and Finland.

112. Spathic Ores. — Spathic or sparry ore is the term applied by metallurgists to the purer and more crystallized varieties of *ferrous carbonate* (CO_3, Fe), while the impure and argillaceous carbonates of the coal measures are known as *clay ironstones*, and if impregnated with much bituminous matter, as occurring in Scotland, the ore is then known as a *blackband* ironstone.

Spathic ores in their purest form, that is, as crystallized "*siderite*," contain 48·27 per cent. of iron, and vary in colour from white to yellow or brown, with a pearly lustre, but are frequently coated superficially with a layer of hydrated ferric oxide produced by the weathering of the carbonate; the streak is white, and when crystallized they occur in the rhombohedral system; in composition they vary much, but manganous oxide is almost invariably present, in some cases to the extent of 50 per cent. or upwards; lime and magnesia are also frequent ingredients, and this ore often contains iron and copper pyrites in sensible proportions, the pig-iron (speigeleisen) produced therefrom most frequently containing small quantities of copper. Spathic carbonate of iron occurs in England in the carboniferous limestone of Durham, Cornwall, and the Brendon Hills, in Somersetshire; on the Continent it occurs in some instances as mountain masses, as in the Siegen district of Prussia, in Styria and Westphalia, and to a smaller extent in Carinthia. This ore is now in considerable demand for the production of speigeleisen, for which purpose large quantities are shipped to South Wales for reduction, where the ore is picked and calcined for the purpose of expelling sulphur before smelting.

The argillaceous carbonate of iron or *clay ironstone* is compact, earthy or clay-like, varying in colour from light brown to black, the latter due to the presence of coaly or carbonaceous matters, amounting in the *blackband* varieties to 10, 20, or even 30 per cent. of the ore; like the spathic ore it consists largely of ferrous carbonate, with carbonate of manganese, lime, and magnesia, silicate of alumina (clay), potash, phosphates and sulphates, iron pyrites, and occasionally also zinc-blende, galena, etc., along with water and organic matter. This ore occurs either in beds of considerable thickness and extent, or in detached nodules in the clay and shales of the coal measures of North and South Staffordshire, North and South Wales, Yorkshire, Derbyshire, Warwickshire, Denbighshire, and Scotland, as also in the lias formation of Yorkshire. Nearly two-thirds of the total amount of the pig-iron produced in Great Britain is derived from this ore.

The *blackband* variety of ironstone often resembles cannel coal in appearance, containing sufficient bituminous matter to effect its own calcination without the further addition of fuel, and after which it contains about 60 per cent. of iron.

The pig-iron smelted from clay ironstone, without admixture with cinder, contains usually from 0·25 per cent. to 1·5 per cent. of phosphorus, and from ·02 per cent. to 0·1 per cent. of sulphur; but if cinder be added to the charge, as practised in South Wales for the production of common forge pig, the sulphur may reach 0·7 per cent.

113. Titaniferous Iron Ore or Ilmenite.—This mineral occurs massive, or forming sands nearly black in colour, and more rarely in rhombohedral crystals; it has a brown streak, and contains oxide of iron, titanic acid, with more or less magnesia; it is a very refractory material, difficult of treatment in the blast furnace, and has accordingly been tried as a material for lining the bed of revolving puddling chambers with tolerable success, and recently it has been treated in the American bloomery furnace for the production of malleable iron direct from the ore.

ANALYSES OF IRON ORES.

	Magnetic Iron Ores.		Red Iron Ores.		Brown Iron Ores.		Spathic Ores.		Clay Ironstone of Coal Measure.			Cleveland Ore.
Locality,	Dannemora Ore.	Dartmoor.	Ulverstone.	Barrow-in-Furness.	Forest of Dean.	Northampton.	Brendon Somersetshire.	Siegen.	Black-band, Low Moor.	Dudley, Gubbin Ore.	Black-band, Monmouthshire.	Eston.
Analyst,	*Ward.*	*Riley.*	*Spiller.*	*Richards*	*Dick.*	*Percy.*	*Spiller.*	*Schnabel.*	*Spiller.*	*Dick.*	*Rogers.*	
Ferric oxide (Fe_2O_3),	27·55	62·20	94·23	94·88	90·05	56·20	0·81	...	1·45	0·40	4·10	3·60
Ferrous oxide (FeO),	58·93	17·32	...	...	...	trace	43·84	43·59	36·14	45·86	43·37	39·92
Manganous oxide(MnO),	0·10	0·14	0·23	0·04	0·08	0·20	12·64	17·87	1·38	0·96	1·50	0·95
Alumina, . . .	0·29	3·81	0·63	0·07	0·14	2·43	0·01	...	6·74	5·86	6·05	7·86
Lime, . . .	0·38	5·52	0·05	0·34	0·06	0·49	0·28	0·08	2·70	1·37	3·00	7·44
Magnesia, . .	0·61	1·82	trace	trace	0·20	0·17	3·63	0·24	2·17	1·85	0·25	3·82
Potash, . . .	...	0·10	...	...	...	...	...	...	0·65	...	...	0·27
Silica, . . .	12·54	9·66	4·90	4·55	0·92	29·07	0·07	...	17·37	10·68	...	8·76
Carbonic anhydride,	0·12	...	...	...	...	...	38·86	38·22	26·57	31·02	30·50	22·85
Phosphoric anhydride,	trace	0·10	trace	0·03	0·09	0·84	...	...	0·34	0·21	trace	1·86
Sulphuric anhydride,	...	...	0·09	...	} traces	...	...	...	trace	trace	...	...
Sulphur, . . .	0·04	...	...	...		...	...	...	...	...	...	0·11
Iron pyrites, . .	...	0·07	0·03	...		...	...	...	0·10	0·10	1·56	..
Water, . . .	0·11	0·62	0·56	0·47	9·22	10·90	0·18	...	1·77	1·08	·58	2·97
Organic matter, .	...	...	...	...	...	...	...	...	2·40	0·90	6·25	...
Insoluble residue, .	...	...	...	..	...	...	...	...	...	...	2·80	..
Percentage of iron, .	62·60	57·01	65·98	66·42	63·04	39·34	34·67	34·18	29·12	35·99	36·49	33·62

CHAPTER VI.

PIG OR CAST IRON.

With but few exceptions, which will be noted under malleable iron and steel respectively, the result of the treatment of iron ores with fluxes and reducing agents in the various furnaces is the production of a combination of iron with carbon, silicon, sulphur, phosphorus, and manganese, with occasional traces of arsenic, copper, titanium, chromium, cobalt, etc., and known as *pig-iron*, which is unforgeable, cannot be welded, and is almost void of ductility; its specific gravity ranging between 7·1 in grey pig-iron to 7·5 in white pig-iron, and melting at an average temperature of about 1530°C. (2786°F.)

In pig or cast-iron, iron attains its maximum degree of carburization, the amount of carbon varying from 2 per cent. to 5 per cent., the lower figure being just beyond the limit (about 1·8 per cent.) of hard cast-steel. Carbon may exist in pig-iron either in a state of chemical combination, or as flakes or crystals of graphite distributed in an uncombined state through the mass, or partly combined and partly graphitic; under these conditions we have various grades of *white*, *grey*, and *mottled* pig-iron respectively (see p. 77). On treatment with acids these varieties behave very differently: *white* cast-iron is almost entirely dissolved, only a very small residue of graphite remaining, the bulk of its carbon escaping in combination with hydrogen, as mixtures of gaseous and liquid hydrocarbons, the latter being highly volatile, of a brown colour, soluble in alkalies, and possessing a most disagreeable odour; while *grey* pig-iron under the same condition deposits almost the whole of its carbon in the form of a graphitic insoluble residue. *Speigeleisen* or mirror iron, sometimes called also specular iron, is the most highly carburized and crystalline form of white pig-iron; its composition has given rise to much investigation as to whether it was not an atomic compound of iron and carbon of the composition Fe_4C, or, as it invariably contains a large proportion of manganese, whether it might not be a tetracarbide, in which a portion of the iron is always replaced by manganese, its formula being $(FeMn)_4C$. Some varieties of white pig-iron, in melting, pass through an intermediate pasty condition, in which the metal is more readily decarburized, and with less oxidation of the iron than occurs when iron is merely heated to redness, or when it is in a perfectly fused state, hence its preference for conversion by puddling into malleable iron. The action of atmospheric air, when blown through molten pig-iron, is to effect the removal of its carbon, silicon, and manganese, as will be described under the Bessemer process for the conversion of pig-iron into steel. Cast-iron is sensibly acted upon or corroded by immersion in sea water, especially if exposed to the combined action of sea water and air; a porous mass remaining having the form of the original casting, but which in some cases after drying is spontaneously inflammable.

Grey pig, if suddenly cooled, becomes white; and hence, on an examination of Swedish pigs, which are cast as rectangular plates in iron moulds, and thus chilled on the surface, it is found that, however grey the bulk of the metal may be, it usually exhibits on fracture a variable depth or skin of white iron, resulting from the chilling effect of the iron mould on the liquid metal, attended with the conversion of the carbon at the chilled surfaces wholly into combined carbon; the white portion is also found to be poorer* in silicon than the upper or grey part. Grey pig-iron, owing to the higher temperature employed in its production, often contains larger amounts of foreign substances, as silicon, aluminum, magnesium, etc., than does white iron smelted from similar mixtures. If both white and grey iron be produced in the same furnace, and descend together to the hearth, the white iron, having a higher specific gravity, will separate and form the bottom layer; hence, on tapping the furnace, the first metal will run out in a sluggish stream, accompanied by showers of sparks, and yielding pigs of white iron; which may subsequently be succeeded by a perfectly fluid stream, unaccompanied by sparks, the product being foundry or grey pig-iron. The low temperature attained in the Swedish charcoal furnace, with the silicious slag produced therein, favours the production of light grey or mottled iron.

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* Crooke's and Rohrig's *Metallurgy*.

The table of analyses of pig-iron given on the next page, serves to show the average amount of its usual constituents, with the variation in its composition.

114. Cast-Iron and Sulphur.—The presence of small quantities of sulphur in cast-iron improves its strength for foundry purposes, but the presence of upwards of ·03 per cent. of sulphur in a pig-iron renders it unfit for treatment by the Bessemer or by the Siemens' open-hearth steel process; the steel produced from such pig being invariably red-short. In the smelting of Swedish gun-foundry iron, a small quantity of iron pyrites is introduced into the blast furnace along with the ordinary charge, whereby the fracture of the pig assumes a peculiar appearance as of grey iron traversed by a network of white iron; the cast-iron so obtained is specially adapted for the casting of ordnance. The presence of sulphur in pig-iron tends to produce whiteness in the pig.

115. Cast-Iron and Phosphorus.—When the blast-furnace is working regularly without the production of a scouring or basic slag, then practically the whole of the phosphorus in the ore, fuel, and fluxes is reduced and passes into the pig-iron, but when a rich scouring slag is being produced in the blast-furnace, then a portion of the phosphorus escapes in combination with the ferrous oxide of the slag. Hence *phosphorus is a most frequent constituent of pig-iron*, ranging between 0·25 per cent. and 1·5 per cent. in the pig smelted from clay ironstones, whilst 2 per cent. to 2·5 per cent. of phosphorus frequently enters into the composition of pig-irons smelted in furnaces working upon heavy burdens of cinder, or in furnaces smelting Cleveland stone for special use in the Basic-Bessemer process.

The effect of phosphorus in pig-iron for foundry purposes is to increase its fusibility, as also the time during which it remains fluid, thus rendering such pig-iron well adapted for the casting of light and ornamental work. Although in small proportions phosphorus is without effect upon the strength

ANALYSES OF CAST OR PIG IRON.

MATERIAL.	Graphitic Carbon	Combined. Carbon	Silicon.	Sulphur.	Phosphorus.	Manganese.	Titanium	Copper.	Iron.
No. 2 pig,	3·18		3·28	0·06	0·06	0·48	0·71	..	92·79
Pig-Iron Smelted from Northamptonshire ore with hot-blast (Henry),	1·150	0·554	1·900	0·414	1·807	0·395	...	...	93·780
Lancashire Bessemer pig, No 2 grey (Author),	2·579	1·175	1·758	0·014	0·038	0·130	...	...	94·304
Bowling No. 1 grey, cold-blast pig (Abel),	...	2·99	0·97	0·05	0·50	...	...	...	...
Cleveland No. 3 pig,	3·13	0·28	0·88	0·17	1·23	0·037	0·140	...	93·66
No. 1 pig, smelted from Hæmatite with 7·57 per cent. of Ilmenite (Riley),	3·31		1·86	0·06	0·08	0·50	1·15	...	93·47
Hæmatite Bessemer pig, No. 1 grey from Cleator, Cumberland (Author),	3·045	0·704	2·003	0·008	0·037	0·309	0·189	...	93·611
German Speigeleisen smelted with coke,	5·04		0·41	0·08	...	7·57	...	0·16	86·74
Mottled iron smelted with charcoal (Rosthorn),	2·02	1·43	0·92	0·04	0·04	2·02	...	...	94·08
Scotch hot-blast pig-iron (Schaffhäutl),	2·45	2·00	2·23	0·18	0·25	0·21	Aluminum 0·40		88·983
Pontypool cold-blast grey pig (Woolwich Arsenal),	2·53	...	1·23	0·08	0·46	0·42	...	...	...
No. 4 Forge hot-blast iron (Stock),	2·719	1·222	1·608	0·031	0·016	0·021	Alumin. and magnesium traces.	Calcium, ·074	94·309

of pig-iron, yet in considerable proportions it renders the metal decidedly weak under a tensile stress.

116. Cast-Iron and Silicon.—Silicon, derived from the reduction of silica in the blast furnace, is present in almost all pig-irons, in amounts varying in ordinary pigs from 0·1 per cent. to 5 per cent., and in exceptional cases even 20 per cent. of this element may be introduced into a pig-iron, the metal then being highly crystalline and silvery white in colour; hot blast and grey irons contain the largest proportion of this element, while, owing to the low temperature produced in charcoal furnaces, the pig-iron produced in such contains a smaller proportion of silicon than occurs when coke is employed as the fuel; its quantity is further always increased when free *silica* exists in the charge, and an insufficiency of lime is added to combine with the excess, or when light *burdens*—that is, a large proportion of fuel to ore—are employed in the furnace. Silicon, like carbon, is capable of existing in the graphitic condition, in which state it may occur in pig-irons smelted with hot-blast from ores difficult of reduction, while white or manganiferous pigs do not hold it in this condition. The presence of this element is very necessary in hæmatite pig-iron intended for the Bessemer process; but its presence in large quantity diminishes the strength of the pig-iron for foundry purposes.

117. Effect of other Metals on Pig-Iron.—The presence of *titanium* in pig-iron imparts additional strength to the metal, and gives a peculiar mottled appearance to the pig; it is rarely present to the extent of more than 1 per cent.

Vanadium has been detected in the pig-irons produced from certain ores of Taberg, in Sweden, oolitic ores of Wiltshire (Riley), etc.; its presence renders the iron soft, and yields an iron well adapted to wire-drawing.

Copper is frequently present in small quantities in pig-iron, especially in those brands (as speigeleisens) smelted from spathic ores; pig-iron containing copper is unfit for conversion into malleable iron or steel, but the presence of a small quantity, not exceeding 0·2 per cent., is said not to deteriorate its quality as a foundry pig.

Arsenic, chromium, aluminum, zinc, etc., are often present in pig-irons smelted from ores containing these metals, the first-named occasionally in considerable amount.

Pig-iron containing *tin* is hard, readily fused, and unfit for conversion into malleable iron, yielding a wrought iron exceedingly *cold-short.*

Manganese is present in most pig-iron (see p. 93, and Analyses, p. 89), for, like phosphorous, the manganese of the iron ore is found after smelting to be partly in the blast furnace slag and partly in the pig-iron; but highly manganiferous pig-irons only result from the smelting of highly manganiferous and easily reducible ores. Manganiferous pig-iron appears to occlude hydrogen more freely, and carbonic oxide less abundantly, than do the less manganiferous irons.

Speigeleisen is a manganiferous pig-iron containing from 5 to 20 or 30 per cent. of manganese. It is a white iron, possessed of great hardness, and often presenting large cleavage planes on fracture. Still more highly manganiferous alloys, containing as much as 80 per cent. of manganese, and known commercially as *ferromanganese,* are now largely prepared for use in the manufacture of very soft mild steel. The production of ferromanganese in the blast-furnace requires, besides suitable ores, a highly basic slag, with a high pressure of blast and the highest attainable temperature of blast and furnace hearth. Its production also involves a very large consumption of fuel, and a much diminished output per furnace.

118. Commercial Classification.—Pig or cast-iron occurs in commerce, either in the form of oblong blocks, or as pigs of about 3 feet in length and of D section. Upon the colour, hardness, brittleness, and character of fracture depends chiefly the classification adopted in commerce of *grey, mottled,* and *white* or *specular* iron. The first variety is again subdivided in the Cleveland district, according to the degree of greyness, into No. 1, 2, 3, 4, 4 forge. No. 1 is the darkest grey, is soft and largely granular on fracture; in Nos. 2, 3, 4 the colour becomes gradually whiter, but duller in lustre, and the metal becomes more finely granular in structure, until it passes insensibly into white iron, which has a more crystalline flaky appearance on fracture, is very much harder;

and, as in specular iron or *speigeleisen*, is largely crystalline, exhibiting large lustrous cleavage planes on fracture. The mottled varieties, which stand intermediate between the grey and white irons, exhibit on fracture a mottled or variegated aspect, from the presence of veins and small masses of white iron embedded, as it were, in a matrix of grey iron. According to the amount of white iron present, the pig is characterised as *weakly* or *strongly* mottled, the latter approximating to white iron in appearance and character.

Grey iron requires a higher temperature (1600°C. to 1700°C.) for its fusion than does white iron (1400°C. to 1500°C.), but it is very fluid when melted, and passes directly from the solid to the fluid condition, while white iron passes through a pasty condition before melting, and the same before solidification after fusion. Grey iron also expands at the moment of solidification, after insinuating itself into the finest lines of the moulds used in the foundry, while white iron contracts under the same circumstances; these qualities have led to the designation of No. 1, 2, and 3 grey iron as *foundry pigs*, while those below No. 3 in greyness are called grey and strong *forge pigs* respectively, since they are only available (except for special castings) for conversion into malleable iron, while No. 1, 2, 3 grey can be applied either to this purpose or to the requirements of the foundry.

The several grades of *foundry pigs* also present well known characteristics, when in the molten state in the founder's ladle. The fluidity of the molten metal decreases as the grade number rises; thus whilst molten No. 1 iron appears in the ladle to be dark and sluggish, giving off neither sparks nor splashes as it is poured into the moulds, No. 2 presents a higher red appearance, pours from the ladle in large sheets, splashes a little, and exhibits an ever varying kind of figured appearance as the metal cools in the ladle. In No. 3 the surface figuring of the molten metal is much less distinct, and it throws out sparks rather abundantly during the period of pouring, while the scum or *kish*, which rises to the surface and separates most largely in No. 1 and less abundantly in No. 2 iron, occurs much more sparsely in No. 3. No. 4, which is the hardest number usually employed by the founder, throws out showers of sparks, and the surface of the molten metal as it stands in the ladle always appears hotter than does the previously described lower numbers.

In the Lancashire district the fifth grade, or strong forge pig, is designated by V, the lower grades being designated in the same manner as in the Cleveland district. In districts where hæmatites are smelted for the production of pig-iron applicable to the Bessemer process, two additional qualities have been introduced, called Nos. 1 and 2 Bessemer pig-irons respectively; these, owing to their comparative immunity from phosphorus and sulphur, are particularly well adapted to the requirements of the Bessemer process for the production of steel, and command a higher price in the market than the other classes of pig-irons.

119. Speigeleisen.—This is a manganiferous pig-iron, often possessing, as noted in Article 112, well marked physical qualities; its fracture especially usually presenting large cleavage planes, though these are not essential to the existence of good speigeleisen. Its essential constituents are from 4 to 5 per cent. of carbon (which exists almost wholly in the combined or dissolved state), with upwards of 6 per cent. of manganese. Commercial varieties of speigeleisen usually contain from 8 to 20 per cent. of manganese, while special samples will contain as much as 30 per cent. of this metal. If the speigel contain less than about 6 per cent. of manganese it is generally considered to be useless for the purposes of the steel manufacture, and more especially for use in the Bessemer process (p. 251).

ANALYSES OF SPEIGELEISEN.

Locality.	Germany.	England.
Graphite, ...	0·27	0·293
Combined carbon, . .	4·02	3·441
Silicon, ...	0·48	0·215
Sulphur, ...	0·05	0·064
Phosphorus, ...	0·26	0·088
Manganese, ...	10·25	8·958
Copper, ...	Trace.	0·012
Iron, ...	84·67	86·917
	100·00	99·988

120. Mine and Cinder Pig.—Pig-iron smelted from ores (*mine*) alone is known as *all mine-pig*, whilst that smelted from puddling cinder and slags is termed *cinder-pig.*

Glazed or blazed pig-iron is a highly silicious and inferior class of metal, usually produced when a large excess of fuel is employed, as during the first blowing-in of a furnace.

121. Strength of Cast-Iron.—The strength of cast-iron under tensile, torsional, transverse, and crushing stresses, fluctuates between very wide limits; and Fairbairn has shown that the strength increases with repeated melting up to the twelfth time, after which a repetition of the fusion decreases the strength. The presence of silicon in pig-iron also diminishes the strength. The experienced eye can often form a crude estimate of the amount of silicon in a pig-iron from the facility with which it breaks when dropped across the Λ block used in breaking the pigs; pig-iron made with hot-blast is also inferior in strength to cold-blast iron, probably from the more complete reduction of the silicon in the furnace at the high temperature produced by the hot-blast. The strongest pig-irons, then, are such as have been smelted with cold-blast from hæmatites containing but small proportions of silica, or from argillaceous ores.

From the published results of the experiments conducted at Woolwich Arsenal, it appears that the tensile strength of cast-iron varies from 4·85 tons to 14·00 tons per square inch, and its resistance to crushing from 22·54 tons to 58·42 tons per square inch of section, indicating the greatly superior strength of cast-iron under a crushing than under a tensile force.

The transverse and the torsional strength of cast-iron are each very low, ranging only from 1·5 tons to 4·5 tons to the square inch, but its shearing strength reaches about 12 tons to the square inch. Annealing diminishes the strength of cast-iron, whilst the presence of sulphur increases, and phosphorus, if in sensible proportions, diminishes the strength of the metal. Engineers generally require the cast-iron used for structural purposes to be such that a bar two inches deep and one inch in thickness, supported on centres 3 feet apart, shall not break under a weight of less than 28 cwt. supported at the centre.

122. Production of Pig-Iron.—The production of pig-iron from iron ore involves two stages; firstly, the preparation of the ore as received from the mine for the *blast-furnace* or *smelting* operation; and secondly, the reduction in the blast furnace of the metallic iron from its chemical combinations, together with its recarburization to pig-iron, and its separation from the earthy matters of the ore.

The first process, as practised in France, Belgium, Germany, and Sweden, includes two distinct operations, that of *washing* or *dressing* the ore for the concentration of its metalliferous portions, together with the subsequent roasting or calcination of this product, whereby water, carbonic acid, sulphur, and other volatilizable substances are eliminated under the influence of heat, or by the combined action of heat and air, leaving a more or less porous mass readily acted upon by the gases of the furnace. In England, however, the ores are not subjected to any preliminary dressing or mechanical treatment prior to *roasting* or *calcination*, and the dressing operations will not be further dwelt upon.

The production of white or grey cast-iron in the blast furnace is not perfectly under control; but for the production of white iron, mixtures of easily fusible ores are employed, so that the charge can be smelted more rapidly, thereby reducing to a minimum the time of contact of the melted metal with the carbon of the fuel; also the proportion of ore to fuel in the charge is increased, and a greater burden of materials maintained; thus, other things being identical, the production of white iron is less costly than grey pig-iron. Owing to the lower temperature employed in its production, white iron does not contain so large a proportion of silicon as the grey pig, but often contains larger proportions of sulphur and phosphorus, and its carbon is almost wholly in the combined state.

123. Calcination.—In this country rich ores, as red hæmatites and magnetites, are not subjected to calcination, such not being necessary, water forming the chief volatilizable substance in this class of ores; in Sweden, however, all ores are subjected to a preliminary calcination before *smelting*. The hæmatites in Lancashire and the north are at once broken up into pieces about two inches square, and charged, along with *fluxes* and *fuel*, into the blast furnace, where the first effect is the expulsion of water from the ore contained in the upper portions of the furnace by the heat of the ascending gases. Other classes of ore are roasted or calcined in *heaps* or *kilns*, in which a careful regulation of the temperature is necessary to prevent the fusion of the ore into a more or less compact mass, or the partial reduction of the metal in carbonaceous ores, as blackband, etc. The effect of the roasting is to decompose to a great extent any *pyrites* present, with the volatilization of the sulphur and other volatile substances, together with the elimination of carbonic anhydride and water, and the conversion of *ferrous oxide* and *ferrous carbonate* into *ferric oxide*, thereby preventing the loss of iron from the formation of slags of ferrous silicate, which occurs readily when silica and ferrous oxide are brought into contact in the furnace, and these silicates are difficult of subsequent reduction. When ferrous silicates or furnace slags, such as forge or mill-cinder, are to be added to the blast-furnace charge for the reduction of iron therefrom, it is usual to subject such cinders to a preliminary roasting in an oxidizing atmosphere, whereby they are largely decomposed and the iron is separated in the form of ferric and magnetic oxides, which are much more easily reducible in the blast-furnace than the original silicates. Also, the roasting of such cinders has the effect of largely expelling the sulphur usually present in them. The loss of weight in roasting amounts to 25 or 30 per cent. with Welsh argillaceous ores; to 50 per cent. in blackbands; to 6 per cent. with red hæmatites; and to about 12 per cent. with brown hæmatites.

The *roasting* or *calcination* in heaps or piles in the open air, or in kilns of various kinds, is conducted in much the same fashion as that described for charcoal burning; the heat being supplied partly from fuel mixed with the ore, and, as in the case of blackband ironstone and other ores containing carbonaceous matters, is assisted by the combustion of such carbonaceous matters; in other cases the kilns are heated by the waste gases of the blast furnace. Roasting in heaps is effected by making in the ground a bed of coal a few inches in thickness, on which is placed a depth of 10 or 12 inches of ironstone, alternating thus, coal and ore, until the pile reaches 4 or 5 feet in height; the process is then conducted by lighting the fire at the base, and damping with small ore those parts of the heap in which combustion appears to be too active or progressing too rapidly. A method adopted on the Continent consists in enclosing the ore and fuel for the roasting operation between vertical walls, in which openings are made along the sides at various heights for the regulation of the heat, the whole forming a kind of kiln.

The blackband ores of Scotland and Staffordshire usually contain sufficient bituminous or carbonaceous matter to effect the roasting, without any further addition of fuel or coaly matter beyond a single layer at the bottom for the commencement of the combustion.

In pyritic ores, the pyrites usually occur in plates, laminæ, or nodules along the planes of stratification of the ore, and Grundman* recommends that the blocks should be placed with these planes vertical in the roasting pile, so as to allow of the more ready escape of the sulphur.

In South Wales, the roasting or calcination is effected in massive kilns built of rough masonry, lined with fire-brick, the bottom of the kiln being formed of cast-iron plates. Arches built in the masonry allow of openings being made at the level of the floor for the extraction of the calcined or roasted ore from the bottom of the kiln, while the process is still going on in the upper zones of the kiln; other openings above these serve for the admission of the necessary amount of air for carrying on the combustion and maintaining the heat required for the calcination. The horizontal section of such a kiln shows two parallel sides of masonry, connected at their two extremities by semicircles; the kilns are much wider at the top than at the bottom. A kiln holding 70 tons of ore and fuel measures 20 feet in length, is 18 feet in height, and 2 feet in width at the bottom, increasing to 9 feet at the top. The operation is conducted by first lighting fires on the cast-iron floor, and covering these to the depth of a few inches with ore (ironstone); in a short time the mass is red hot, when a further layer of a mixture of ore, with about 5 per cent. of small coal, is placed over the heated mass, and so on, fresh layers or strata of the mixture being added as soon as the previous layer has attained to a red heat. By the time the kiln has been entirely filled, the layers in the bottom are ready for drawing, which is effected through the openings already mentioned in the base of the kiln. In this manner the charge of ore takes from three to four days for its calcination.

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* Grundman. *d. Entschwefl der Eisenerze.*

Kilns erected at the Newport Works, Middlesbrough, are cylindrical in section, built up of wrought-iron plates, and lined with fire-brick. The lower portion of the kiln tapers towards the base, and has openings all round the lower part for the admission of air and the withdrawal of the calcined *stone* or ore, which is directed to the openings by a central cone having its apex upwards. Each kiln has a capacity of 15,800 cubic feet, and holds about 630 tons of material.

In the self-coking blast furnace proposed by Mr. Ferrie of the Monkland Ironworks, the top is closed and surmounted by an arrangement for the coking of the fuel or calcination of the ore, heated by the combustion of the waste gases drawn from the top or throat of the blast furnace. Mr. Brown of the Shotts Iron Company has also introduced a furnace of this character, with a somewhat different arrangement for effecting the combustion and utilizing the heat of the blast-furnace gases, in an upper chamber or kiln surmounting the stack of the furnace. The Swedish calciner, heated by the waste gases of the blast furnace, consists of a cylindrical slightly conical shaft, formed of an exterior mass of ordinary brickwork lined in the interior with fire-brick, the whole supported by hoops or bands of wrought-iron. The outer wall is traversed by numerous horizontal openings for the escape of moisture, etc., and at the base are a series of openings through which the charge is withdrawn; the gases from the blast furnace are introduced at the base of the kiln by 16 nozzles, and a little above them are the openings controlled by dampers for the admission of the necessary air for the combustion of the gases, and above which again are a series of holes for the introduction of the bars used in breaking up the charge in cases of clotting from excessive heat or other cause.

The object of the roasting or calcination of iron ores being the expulsion of volatile ingredients, etc., leaving the ore as a porous mass, it is necessary that the temperature do not rise sufficiently high to clot or melt the ore, otherwise it becomes dense and impervious to the gases in the blast furnace. Ores containing silica, easily fusible silicates, or manganiferous compounds, have a tendency to clot; while calcareous ores, and compact ores rich in iron, bear a higher temperature, and a more prolonged calcination without matting or fusing together. Ores intended for the production of forge pig are more strongly calcined or roasted than if for foundry pig.

124. Weathering.—Very pyritous ores, such as are also accompanied by shales, instead of being calcined, are subject to a *weathering* action, in which the ore, placed in heaps, is exposed to the action of the weather for periods of three or four months, but varying with the amount of impurity, extending in some cases to three or four years; if containing much sulphur, the heap is frequently watered, so as to dissolve and remove the sulphates formed by the oxidation of the pyrites, etc.

125. Reduction or Smelting.—After calcination, the ore is broken into pieces more or less uniform in size; these pieces in the hæmatite districts are, as already stated, cubes of about 2 inches in diameter; in the Cleveland district, where the furnaces are larger and the fuel a hard coke, the pieces are larger, measuring from 4 inches to 6 inches; in Sweden, again, the furnaces are of a small description, and the pieces are not more than inch cubes. This breaking up of the ore after calcination is effected in special ore or stone crushers, or between rollers, appliances which have superseded the old stamps.

The blast furnace being at work, or, as it is technically called, *in blast*, it is kept filled to the top, or *throat*, by continually adding to the furnace the smelting mixture of *ore, fuel*, and *flux*, as the charge works down. The supply of air or *blast*, under a pressure of from 3 to 9 lbs., in furnaces worked by coke, or of 1½ to 2 lbs. in charcoal furnaces, is maintained through the twyers near the bottom of the furnace, except during the intervals when the top is opened for the introduction of the charge, when the blast is shut off.

The oxygen of the air, injected through the twyers, meeting with incandescent fuel, is in a great measure immediately converted into *carbonic anhydride*, with the production of the maximum amount of heat, within a short distance of the twyers; the carbonic anhydride so produced, ascending towards the throat of the furnace, passes over a large mass of heated fuel, and is quickly reduced to *carbonic oxide;* thus,

$$CO_2 + C = 2CO,$$

each volume of carbonic anhydride forming two volumes of carbonic oxide, with a corresponding reduction of temperature in the lower part of the boshes where the change is effected. The carbonic oxide so produced, along with, perhaps, a smaller proportion derived from the deoxidation in the same manner of the carbonic anhydride expelled from the limestone used as a flux, then becomes the *principal* and *active* reducing agent of the blast-furnace. The carbonic oxide in ascending meets the mixture of heated ore and flux, which is descending towards the hearth. The porous oxide of iron, thoroughly heated and calcined while in the upper part of the furnace, is readily permeated by the ascending gases, with the reduction of metallic iron; thus,

$$Fe_2O_3 + 3CO = 3CO_2 + 2Fe,$$

in addition, a smaller proportion of iron is probably reduced directly by the action of the fuel upon the ore at the high temperature existing in the furnace; thus,

$$2Fe_2O_3 + 3C = 4Fe + 3CO_2.$$

The iron thus reduced to the metallic state, in passing downwards towards the hearth of the furnace, comes into contact with a large amount of heated fuel, and combines with a varying amount of its carbon; a further carburization being probably effected by the decomposition of carbonic oxide, carburetted hydrogens, and possibly cyanogen compounds, by the reduced metal, with the production of the fusible compound of carbon and iron, with various impurities, constituting what is known as pig-iron. It has been attempted to mark out, with some considerable accuracy, the various zones or limits within which the specific reactions occurring in the blast furnace are confined; but any such definite mapping must always be unsatisfactory, since the same furnace yields, at the same depth from the mouth or throat, very different products on different occasions. The cycle of operations by which the oxygen of the blast is first converted into carbonic anhydride, and then almost immediately reduced to carbonic oxide, which in its turn, again becomes carbonic anhydride by its reaction upon oxide of iron, is repeated as the gases ascend through the furnace, so long as the temperature remains sufficiently high to effect the decompositions; the escaping gases, however, always contain a large proportion of carbonic oxide, which burns with its characteristic flame, though masked by the volume of yellow flame emitted at the mouth of the furnace if the gases are allowed to escape; or it forms a valuable source of heat, to be utilized for various purposes, as heating of the blast, or calcination of the ore, etc., if collected at the top of the furnace, as is now the usual practice in this country.

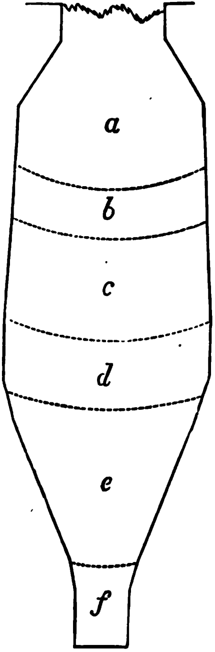

Fig. 18.—ZONES OF BLAST FURNACE.

Fig. 18 is a diagram of the blast furnace divided into zones, as communicated in a paper by Mr. Lowthian Bell to the Institute of Civil Engineers,* showing the distribution of temperature and state of the materials at various depths from the throat of the furnace. The upper portion of the zone *a* is occupied by the raw materials charged into the furnace, which are there being heated by the ascending gases; towards its lower boundary (and within 20 feet of the top of the furnace), the mass is at a *dull red heat*, and the ore suffers reduction by contact with carbonic oxide with the production of a spongy metallic mass; the zone *b* is at a *red heat*, and the limestone here suffers decomposition; *c* is at *full red-*

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* Proceedings of the Institute of Civil Engineers, 1872.

ness, and the descending spongy metal begins to absorb carbon from contact with the fuel, which absorption continues through the next zone *d*, where the temperature has attained to *bright redness*, and it is probably in this zone that sulphur, phosphorus, silicon, etc., are to a large extent reduced from the materials of the charge, and combine with the pig-iron; in the boshes *e* the heat attains to *very bright redness*, and the descending charge of spongy metal, with slag-forming materials, undergo thorough fusion in their descent through this zone; and in the crucible or hearth *f*, where the heat is at its greatest intensity or *whiteness*, the fused metal and slag separate, the fluid pig-iron forming the lowest stratum, above which is the layer of fluid slag.

But irregularities in the working of the furnace, and the temperature therefore, at any depth below the throat of the furnace at any time, are effected (1) by very small differences in the composition of the ore, fuel, and fluxes at the different periods when the observations are made, (2) by variations in the initial temperature of the blast, (3) want of care in charging, and (4) even atmospheric conditions exert an influence upon the working of the furnace. The last-mentioned influence alone is sufficient to make a difference of 5 per cent. in the consumption of fuel required to produce a given quality of pig-iron from the same ores. The above tabulated order of the zones of action in the blast furnace can therefore only represent the sequence of the several zones without absolute regard to their depths from the furnace throat.

As already stated, the quality or grade of pig-iron produced in the blast furnace from any mixture of ores, fuel, and fluxes, cannot be absolutely pre-determined, but generally the use of easily reducible ores, and heavy burdens (a large proportion of ore to fuel) with a reduced temperature of the furnace will yield the higher numbers or white-iron, whilst the substitution in the furnace of a larger proportion of fuel to ore (light burdens) with an increased temperature of the furnace will make a grey and more silicious pig-iron.

The silica, clay, carbonate of lime, and the earthy matters usually accompanying iron ores, as also the earthy matter or ashes of the fuel, would descend along with the reduced metal to the hearth of the furnace, and there remain mixed with it, unless some other substance were introduced capable of combining with these, and producing therewith a fusible compound or *slag;* such a substance is the flux, usually limestone, which is employed, the gangue of the ore being essentially silica, or a silicious mineral, as clay, etc. The flux so added (in addition to promoting the separation of the metal from the *slag* or *cinder* in the hearth of the furnace), by combining with any free silica in the charge, prevents also the loss of iron, in the form of basic ferrous silicates, which would otherwise be produced, as the mixture passed through the zone of most intense heat near the twyers; but if too much limestone be added to flux the silica, then the slag becomes too calcareous, is fusible only with difficulty, and the metal separates imperfectly. If the gangue of the ore be calcareous, then the ores are mixed with others containing silica or clay, such as *forge cinder*, or the roasted slag from the puddling furnace is introduced, though the iron produced from these latter is of an inferior kind, as will appear after consideration of the puddling process. By thus adding a suitable material to flux, or render the gangue fusible, the pig-iron separates from the slag in the hearth of the furnace, the latter rising to the top of the bath of molten metal, and protecting it from oxidation by the action of the blast. The slag is allowed to run away through an opening, to be presently described, and the metal is tapped out at intervals of twelve hours in South Staffordshire, or in the hæmatite districts of the north, every six hours; for this purpose, the blast is turned off, the tap hole broken open by an iron bar, and the metal run into a series of grooves, furrows, or channels, formed in the sand of the floor, near the furnace, or into cast-iron moulds; the furrows are of D section and arranged in parallel rows, the top ends of each row communicating with a common channel, along which the metal runs to supply the furrows in that row; this channel or *feeder* is hence known as the *sow.* In Sweden the metal is cast in rectangular plates in cast-iron moulds, the brand being cast on the under side of each plate or pig.

126. Slags.—Blast-furnace slags differ very widely in physical characters and chemical composition, according to the character of ore and fuel employed, the quality of iron produced, whether light or heavy burdens are being worked, and according as hot or cold blast is employed. Slags accordingly occur varying in colour from almost white or grey, through all shades of brown, yellow, green, and blue to black, the whiter slag, as a rule, accompanying the production of grey iron, in furnaces working with light burdens, that is, a large proportion of fuel to ore and fluxes; while black slags indicate usually (though not invariably) a loss of iron, and a furnace working heavy burdens with the production of white iron. The same slag may be vitreous, stony, or vesicular in structure, according to the manner in which it has been cooled, quick cooling facilitating the production of the vitreous form, with a conchoidal fracture and more or less transparency at the edges, while slow cooling tends to make the slag stony, dull, opaque, and porphyritic in appearance. These characters, as well as the fusibility and fluidity of the slag, are also powerfully influenced by its composition; those slags in which earthy matters, as lime, magnesia, etc., occur in excess, are the least fusible, are of a dull stony character, and disintegrate spontaneously on exposure to air and moisture, while the presence of ferrous and manganous oxides, with large proportions of silica, form slags, termed by the workmen *scouring* slags; and in which the fluidity and fusibility are more perfect. A considerable proportion of alumina gives to the slag the opalescent character so frequent in the slags of Staffordshire furnaces smelting clay ironstones from the coal measures.

Blast-furnace slags are essentially double silicates of lime and alumina, in which the lime is more or less replaced by magnesia, ferrous, or manganous oxide, and the silica is sometimes partially replaced by alumina; they also contain about 1 lb. of potash per ton of slag, with probably some soda, as also sulphur, the presence of the latter element being promoted by the presence in the slag of manganous oxide and of lime. Analyses of a slag frequently found both in hot and cold-blast furnaces of South Staffordshire give a composition corresponding to the formula, $2R_2O_3, 3SiO_2 + 6 (2RO, SiO_2)$, where R_2O_3 is a metallic sesquioxide, chiefly alumina, and RO a metallic protoxide, as lime, magnesia, ferrous, and manganous oxide; and making these substitutions, the formula becomes $2Al_2O_3, 3SiO_2 + 6\ (2CaO, SiO_2)$; in this slag the oxygen of the bases is *equal* to the oxygen in the silica, but the oxygen in the protoxides is *double* that of the sesquioxides. When slags containing calcium, barium, or manganous sulphides, are suddenly cooled by throwing water upon them, the sulphide is decomposed thus:—$CaS + OH_2 = CaO + SH_2$, the presence of the sulphur under this treatment being readily recognised by the odour of the evolved sulphuretted hydrogen (SH_2). A much more silicious slag than the above, and represented by the formula $Al_2O_3, 3SiO_2 + 3\ (CaO, SiO_2)$, is largely produced in charcoal furnaces.

The following table is collected from Percy's *Metallurgy of Iron*:—

ANALYSES OF BLAST-FURNACE SLAGS.

	Average of the analyses made by Mr Riley at Dowlais, from 13 furnaces working with hot blast.	Slag from a cold-blast furnace working with coke. (*Percy*).	Swedish charcoal furnace producing Bessemer pig-iron. (*Ullgren*).	A scouring slag like black bottle glass.
Silica, . . .	41·85	39·52	46·371	41·11
Alumina, . .	14·73	15·11	4·301	13·45
Ferrous oxide, .	2·63	2·02	0·950	6·44
Manganous oxide,	1·24	2·89	1·860	0·66
Lime, . . .	30·99	32·52	38·640	29·82
Magnesia, . .	4·76	3·49	7·400	4·75
Potash, . .	1·90	1·06	0·300	1·84
Calcium, . .	1·15	2·15	...	1·34
Sulphur, . .	0·92		0·030	
Phosphoric acid,	0·15	...	Traces	0·15
Soda, . . .	...	...	0·138	...
	100·32	98·76	99·990	99·56

The presence of various metallic oxides in the slags impart to them characteristic colours; thus manganous oxide produces a violet or amethyst colour when the slag is seen in mass, but not observed when the slag is in the vesicular condition. Manganous sulphide gives a yellow or brownish-green colour, and oxide of iron renders the slag green or black in colour; while alumina, zincic oxide, or sodic sulphide are said to impart a blue colour to the slags.

127. Composition of the Blast-Furnace Gases.—The composition of the gases present in the blast furnace has been investigated at different times by Bunsen, Ebelmen, Scheerer, Playfair, Tunner, Schafhaütl, Rinman, and others. The gases which escape from the furnace mouth are not essentially different, whether hot or cold blast is employed, except that in the case of hot blast using raw coal as the fuel, the gases will contain traces of volatile products arising from the distillation of the coal in the upper zones of the furnace. The following table, collected from the work of Dr. Percy, gives the composition of the waste gases from the tops of three blast furnaces, in which raw coal, coke, and charcoal, respectively, are the fuels employed, all employing limestone as the flux, while the first is smelting calcined argillaceous ores, the other two smelting brown hæmatites, and in the first the blast is heated to 626°F., in the second to 212° F., and in the third cold blast is employed.

COMPOSITION BY VOLUME OF BLAST-FURNACE GASES.

FURNACES.	Nitrogen.	Carbonic Anhydride.	Carbonic Oxide.	Marsh Gas.	Hydrogen.	Olefiant Gas.	Analyst.
1. Alfreton, England,	55·35	7·77	25·97	3·75	6·73	0·43	Bunsen and Playfair.
2. Seraing, Belgium,	57·06	11·39	28·61	0·20	2·74	...	Ebelmen.
3. Clerval, France,	57·79	12·88	23·51	...	5·82	...	Do.

From these figures it appears that the gases have essentially the same composition in the different cases; the nitrogen derived from the air, introduced as blast, passing through the furnace unaltered, and forming more than one-half of the volume of the gases, while carbonic oxide forms 25 per cent. of their volume; the other combustible gases consisting of hydrogen, marsh gas, and olefiant gas, all deriving their hydrogen chiefly from the decomposition of the water vapour carried in by the blast; in addition to these there are small quantities of cyanogen.

The following table, giving the composition of the gases at various depths below the mouth of the furnace, as taken from the Alfreton furnace (which is 40 feet in height, worked with blast, heated to 330°C. (626°F.), under a pressure of 6·75 inches of mercury, and smelting materials as above), shows the proportion of carbonic anhydride to carbonic oxide to be continually diminishing with the increase in depth below the mouth; and in the upper portion of the hearth (fifth column), the gases consist almost wholly of nitrogen and carbonic oxide, with a small proportion of hydrogen. Charcoal furnaces, owing to the light and readily combustible nature of the fuel, yield carbonic oxide even at the lowest level, and a few inches above the twyers carbonic anhydride is almost absent, while the amount of carbonic anhydride rapidly increases in the upper portion of the furnace charge.

ALFRETON FURNACE.	Depth in English feet below the mouth.				
	8	14	20	24	34
Nitrogen	54·77	50·95	60·46	56·75	58·05
Carbonic anhydride	9·42	9·10	10·83	10·08	0·00
Carbonic oxide	20·24	19·32	19·48	25·19	37·43
Marsh gas	8·23	6·64	4·40	2·33	0·00
Hydrogen	6·49	12·42	4·83	5·65	3·18
Olefiant gas	0·85	1·57	...	...	...
Cyanogen	...	...	...	Trace.	1·34

The total weight of the gases passing from the throat of a Cleveland blast furnace 80 ft. in height amounts to nearly 7 tons for each ton of pig-iron made in the furnace, and the calorific power of these gases is equal to that produced by the combustion of about 11½ cwts. of coal.* The blast furnaces are now generally worked with closed tops, in which case the gases are conveyed from the furnace throat to the hot-blast stoves, where they are burnt for heating the blast in the manner described in the following chapter, whilst other portions of the gases are consumed under steam boilers for the generation of steam, and in coke ovens for the production of coke.

The gases which escape or are collected at the mouth of the blast furnace carry over with them considerable quantities of a fine dust, consisting largely of *silica*, *ferric oxide*, *alumina*, and *lime*, with smaller proportions of manganic oxide, magnesia. potash, soda, calcic sulphate and phosphate; and in smelting iron ores containing zincic oxide, considerable quantities of zinc fume or zincic oxide collect in the pipes or culverts through which the gases pass, and requires to be removed at intervals, when the zincic oxide so obtained is sold for the extraction of metallic zinc.

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* *Proceedings Cleveland Inst. of Engineers*, 1882.

128. Reduction of Phosphorus.—It is observed that in smelting ores containing phosphoric anhydride under conditions favourable to the perfect reduction of the iron, that is, when but little ferrous oxide is allowed to remain in the slag, that at the same time phosphorus is absent from the slag, while the pig-iron produced is contaminated with phosphorus; but if the conditions be reversed, and a large quantity of the iron be left unreduced in the slag, it will at the same time be accompanied by the phosphoric anhydride, if any be present, while the pig-iron produced will be comparatively free from phosphorus. It thus appears that the conditions most favourable for the perfect reduction of the iron are exactly such as are required for the reduction of the phosphoric anhydride, with the introduction of the phosphorus into the pig-iron produced. For this reason *cinder-pig*, that is, the iron produced from smelting mixtures containing a considerable amount of cinder or slag in addition to the ore, flux, and fuel, is always impure from the presence of phosphorus derived from the cinder so added. The pig-iron produced from pure ores or *mine* without any admixture of cinder, is called *all-mine-pig* to distinguish it from the above.

Phosphorus, unlike sulphur, is not affected during the calcination of the ores, hence the total amount of this element as originally present in the ore, fuel, or fluxes, passes into the blast-furnace, and in the ordinary working of the Cleveland furnaces about 90 per cent. of the phosphorus present in the furnace charge is reduced and passes into the pig-iron, whilst only about 10 per cent. of it passes out into the slag. The presence of an excess of lime in the slags does not appear to affect the proportion of phosphorus entering the pig-iron.

129. Reduction of Sulphur.—Sulphur, as noted in p. 96, is largely eliminated from iron ores during the process of calcination, whilst in the blast-furnace a high temperature and a liberal use of lime, so as to produce a calcareous slag, have a decided tendency to pass the sulphur into the slag, most probably in the form of calcic sulphide. Hence white-iron, which is produced at a lower furnace temperature, and is accompanied by a more fluid and silicious slag than is grey-iron, also contains more sulphur than the latter—a high temperature and a calcareous slag being favourable to the elimination of the sulphur from the pig-iron.

130. Smelting of Speigeleisen.—Until a very recent date this variety of pig-iron (see page 93) was produced in comparatively few localities, it being considered that its manufacture could only be successful where certain *spathic ores, brown iron ores* formed by their decomposition, or the *Franklinite* of New Jersey, U.S., were the subject of the smelting operation; *i.e.*, its manufacture depended upon the supply of an ore which contained iron and *manganese* in considerable quantity, and at the same time was practically free from sulphur and phosphorus. The chief European localities in which spathic iron ores occur are Styria, Lölling, and Carinthia in Austria; Siegen and Musen in Rhenish Prussia; Hungary, Hanover, Russia, and in the Brendon Hills of England, the ore of the last named being worked by the Ebbw Vale Iron Company, who, until the past few years, enjoyed a monopoly for the manufacture of speigeleisen in England; but more recently, ores capable of yielding speigeleisen have been imported from Spain, and smelted at the Atlas Works, Sheffield. Speigeleisen is also now produced in the furnaces of Messrs Bolcklow, Vaughan, and Company, and many others. The *magnetites* of Sweden, although practically free from sulphur and phosphorus, and some of them containing considerable proportions of manganese, are not sufficiently rich in the latter to yield speigeleisen in the blast furnace; yet, latterly, certain Swedish ores, as those of Schisshyttan, which are said to yield from 13 to 20 per cent. of manganese, have been mixed with magnetic iron ores and smelted for the production of speigeleisen.

For the production of speigeleisen from spathic ores in the Siegen district of Rhenish Prussia, the ore is carefully picked to free it from copper pyrites, after which it is roasted or calcined in kilns, which are charged with alternate layers of ore and carbonaceous matter, such as coke, cinders or charcoal refuse. The kilns are fired from the bottom, and kept in continuous action by raking out the ore from the bottom of the kiln as soon as the calcination is completed in that zone, at the same time continually supplying the place of the materials so removed by fresh ore and fuel added at the top of the kiln. The calcined ore is smelted in the blast furnace with the addition of a large proportion of lime (usually burnt), and only small quantities of clay-slate; in this manner *basic* slags are produced, and the reduction of the silicon in the furnace is greatly impeded. Coke or charcoal is the fuel employed. If the slags be too rich in silica, the latter combines with the manganese, which thereby largely escapes reduction, and grey or mottled iron only is produced in the furnace; and, again, if the temperature be too low, and the burden too heavy, then white iron only is produced. It is thus manifest that, with a suitable ore, the production of this variety of pig-iron requires considerable care, and is not even then perfectly under the control of the furnace manager, slight fluctuations in the temperature and pressure of the blast changing the make or yield from speigeleisen to grey, mottled, or white iron.

131. Ferromanganese.—The production on the large scale of iron with carbon and manganese, or of a ferromanganese which shall be richer in manganese than the ordinary speigeleisen, has become necessary for the successful production of the very soft, mild steel now manufactured by the open-hearth and the Bessemer steel processes. Hence instead of being a crucible operation, as first carried on by Mr. Prieger of Bonn, or manufactured by the reduction of manganous carbonate by charcoal on the bed of a Siemens' furnace, the production of ferromanganese has become a regular blast-furnace operation.

The term *Ferromanganese* is now generally applied to all compounds of carbon, iron, and manganese, in which the latter metal forms more than 20 per cent. of the alloy, whilst it often attains to 80 or 85 per cent., and the term speigeleisen is retained to designate similar alloys which contain, however, not more than 20 per cent. of manganese.

For the production of ferromanganese in the blast furnace, ores rich in manganese are required, and thus, until recent years, this manufacture on a large scale was confined to certain French and Austrian works which smelted manganiferous Sardinian or Spanish ores containing from 10 per cent. to 40 per cent. of manganese; but now, as already stated, the alloy is largely produced in England. Besides special ores, however, the production of ferromanganese involves a very much larger consumption of fuel in the furnace than is necessary when working upon ordinary grades of pig-iron; besides which the highest temperature of blast attainable by the use of fire-brick stoves is necessary, the ordinary pressure of blast is also increased, whilst a much more basic slag is necessary, and hence the furnace is burdened with a large proportion of limestone.

The yield of the blast furnace making ferromanganese is very considerably reduced, often not exceeding about 25 per cent. of the amount which the furnace would make if working upon ordinary pig-iron.

132. Scaffolding, Bears, etc.—Scaffolds or collections of the smelting materials, arising from various causes, occur occasionally in the interior of blast furnaces, interfering with their proper working by obstructing the blast and free escape of the gases, with a consequent cooling of the furnace and thickening of the slags; they also prevent the proper descent of the charge to the twyers; and with the melting and withdrawal of the charge below the scaffold, together with the increasing weight of the charge above, the obstruction very frequently gives way, with the sudden descent, technically called a *slip*, of the charge to the hearth. These obstructions may arise from the faulty shape of the interior of the furnace, from the formation of a too difficultly fusible slag, the presence of too refractory ores, bad fuel—as a weak and friable coke which falls to powder under the weight of the superincumbent materials—or to imperfect charging apparatus, by which the larger pieces of the coke are collected around the sides of the furnace, while the ore is distributed towards the centre. From whatever source arising, these obstructions are exceedingly troublesome, and attended with great difficulty in blast-furnace working.

From the sides and bottom of the hearths of blast furnaces that have been in blast some time, and then blown out, are frequently extracted large ferriferous masses known as *bears*, the composition of which is very various. They often contain iron, silicon, manganese, graphite, copper, red crystals of cyano-nitride of titanium, nickel, cobalt, and occasionally other rare metals.

133. Blowing-in a Furnace.—When commencing to work a new furnace, it is necessary that the masonry be thoroughly dried, and that this be not effected with too much rapidity, otherwise a fear of cracking the masonry arises. When it has been thoroughly dried, the operation known as *blowing-in* the furnace is commenced, for which purpose a quantity of wood is first introduced, and covered over with a considerable depth of coke, on which are superposed layers of coke and limestone, succeeded by a very light burden of ore; the furnace being now about one-third filled, the wood is ignited, and when fairly in combustion the furnace is filled to the top with a light burden of ore, fuel, and flux, and the blowing commenced at first very gently, the amount of blast and burden of ore being gradually increased for a few days, when the normal burden and rate of driving may be attained.

134. Blowing-out of a Furnace.—When a blast furnace has been in blast or uninterrupted regular work for some time, and then requires to be stopped either for repairs or for other causes, the furnace is said to be "blown-out." In order to blow-out a furnace it is the practice to gradually reduce the burden, *i.e.*, to increase the proportion of fuel to ore introduced into the furnace, in which manner the temperature within the furnace is increased and smaller obstructions, such as scaffolds and the like, are melted down. The pipes and fittings around the throat of the furnace are removed, then charging is discontinued and the furnace is allowed to burn down, care being observed to take the last tapping of fluid metal from the lowest possible point of the hearth, so as to prevent any unnecessary collection of metal being found on the hearth when the tymp is taken down for clearing out the last portion of the contents of the furnace.

CHAPTER VII.

THE BLAST FURNACE, HOT-BLAST STOVES, Etc.

Notable amongst the improvements of recent years is the general introduction in this country, and in America, and wherever strong, hard coke can be obtained for fuel, of the larger furnaces, of the cylindrical or cupola type measuring from 70 ft. to 100 ft. in height, with capacities of from 25,000 to 40,000 cubic feet. The use also of higher temperatures and pressure of blast has become general, and hence the hot-blast stoves, notably of the fire-brick or regenerative type of Mr. Cowper and of Mr. Whitwell have been much improved and more generally adopted, to the exclusion of cast-iron pipe stoves from most, except of the older and smaller furnaces. The effect of these alterations in blast furnace practice has been a considerable reduction in the consumption of fuel per ton of pig-iron made, and an increased make of iron per furnace.

135. Blast Furnace.—The older blast furnaces were huge structures of stonework, shaped outside in the form of truncated four-sided pyramids, having walls of immense thickness, consisting of an outer structure of heavy masonry pierced by horizontal openings for the escape of moisture, inside of which was a second shell of brickwork set in cement, which, in its turn, enclosed the inner wall of fire-brick set in fire-clay, from 15 inches to 18 inches in thickness, and forming the inner wall or lining of the furnace; between each of these shells or casings of masonry was left a space which was filled with sand or slag, so as to allow of the necessary contraction and expansion of the several parts of the structure with the change of temperature. But during the past twenty years, one of the most marked features of blast furnace construction has been the reduction effected in the mass of materials employed in their erection; instead of the massive walls of brickwork or masonry, the shaft is now formed of an outer casing of iron plates, lined in the interior with but a few inches of brickwork, the bricks being carefully dressed, faced, and made to the curve at each course; while this shaft, instead of resting on massive masonry pillars, is often carried upon cast-iron columns; at the same time the hearth of the furnace has been continually increasing in diameter. The hearth and boshes require to be of the most refractory material, being subjected alike to a most intense heat and to the corrosive action of the fluid slags; in Norway and Sweden these parts are often lined with a mixture of powdered quartz, fire-brick, and fire-clay well rammed in; but in England fire-brick is usually employed, the bottom of the hearth being formed of large blocks of sandstone or fire-brick built in the form of a flat inverted arch, forming a slight concavity upwards, thus preventing its being pressed upwards by the fluid metal getting beneath it.

The construction of the modern blast furnace varies much both as to shape, size, and the proportion of its parts, having regard to the nature of the ore to be smelted, of the fuel employed, whether charcoal or coke, whether hot or cold blast, and rapidity of driving, that is, the amount of air blown into the furnace in a given time; formerly the practice was to adopt open topped furnaces, but in England close topped furnaces, with an arrangement for taking off the gases, are now almost universally adopted.

The old type of furnace, still retained in Sweden, with only minor modifications of form, consisted of a vertical chamber or shaft open at the top and circular in section, formed as illustrated in No. 1 of fig. 19 by two truncated cones or funnels joined at their widest part or bases, which junction is known as the *boshes* of the furnaces, the part above the boshes being called the *stack;* while the *throat* or top of the *stack* is surmounted, when the furnace is open topped, by a sort of small chimney of brickwork called the *tunnel head,* supported by iron stays or boiler plates. Around the throat of the furnace is a gallery, forming a platform for the delivery of the charge, to be introduced into the furnace through openings in the tunnel head or some of the other arrangements subsequently described. The lower cone or sides of the boshes may be continued directly down to the base, or, as is more usual, its lower end is somewhat enlarged, constituting the *hearth* of the furnace; around the top of the hearth are openings, from

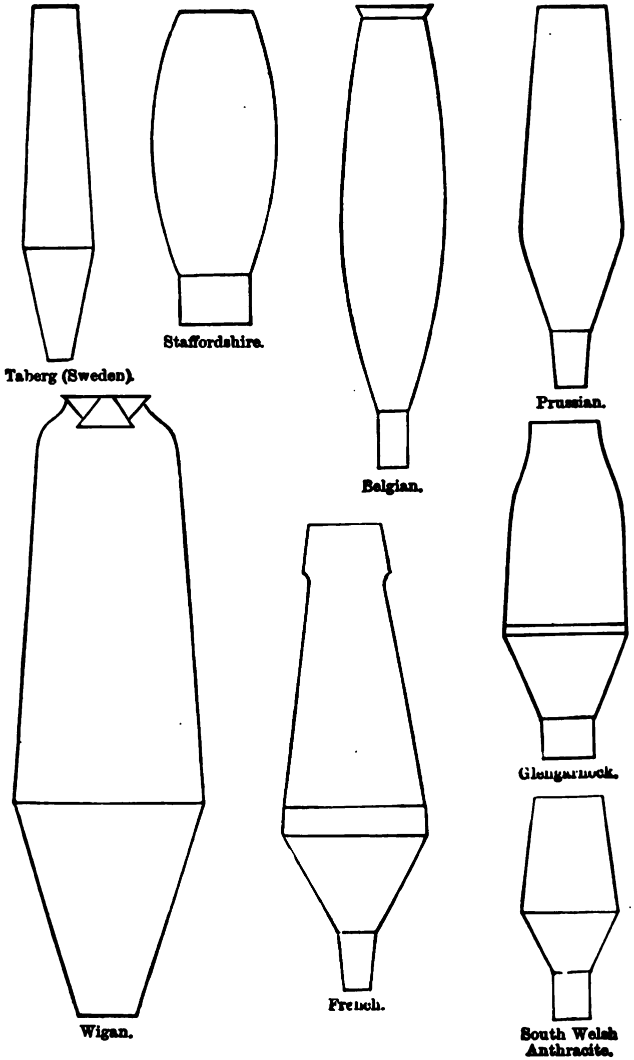

Fig. 19.—Varieties in the Dimensions and Internal Forms of the Blast Furnace.

three to six in number, for the introduction of the *twyers* or pipes through which the blast is introduced; in many furnaces of Staffordshire, Wales, etc., the front or tapping side of the hearth is continued forward beyond the vertical line of the walls of the hearth proper, fig. 20; the cavity so formed, called the *fore-hearth*, is dammed up in front by some refractory material supported by a *dam-plate* of metal, and the arch over the opening so formed into the hearth or crucible of the furnace is called the *tymp arch;* on the under side of the tymp arch is placed a cast-iron box, inside of which is a curved wrought-iron pipe, through which flows a continuous stream of water, so as to keep it cool, and enable it better to sustain the great heat to which it is exposed, as also the corrosive action of the slags, which are continually flowing out beneath it. As the reduction or smelting proceeds, the slag and metal descend to the hearth, where the slag rises to the surface of the metal, and as the hearth fills runs over through a notch in the dam-plate called the *cinder notch,* and is received in trucks with movable sides called *cinder tubs,* which carry it at once to the cinder heap, or it is sometimes cast in blocks, and used for building purposes. In small furnaces this cinder notch is replaced by an inclined plane in front of the dam-plate, called a *cinder fall,* down which the slag is allowed to run and solidify, when it is broken up and removed by hand. A vertical notch 12 inches or 15 inches in length, stopped with sand or clay, is made in the side of the dam, forming the *tapping hole,* which can be readily opened by striking it with a pointed bar, and reclosed after the metal is tapped by the insertion of a clay stopping held on the end of a bar. The opening between the top of the dam and the tymp arch is closed during the working, with the exception of a small opening left for the escape of slag.

Instead of the sharp angles indicated above, as existing at the boshes and the top of the hearth, modern practice has adopted for the internal shape a more or less regular curve from the hearth to the throat of the furnace. All attempts to arrive at the best form of interior from theoretical considerations alone, have been attended with disappointment; it is, however, necessary that the furnace should contract from the widest part or boshes to the hearth, since in this part the charge is gradually decreasing in volume, due to the reduction and fusion of the metal; and also the diameter is so great that for convenience in charging, and to allow of the proper distribution of the charge, it is necessary that the mouth be contracted. Fig. 20 is a vertical section of a blast furnace

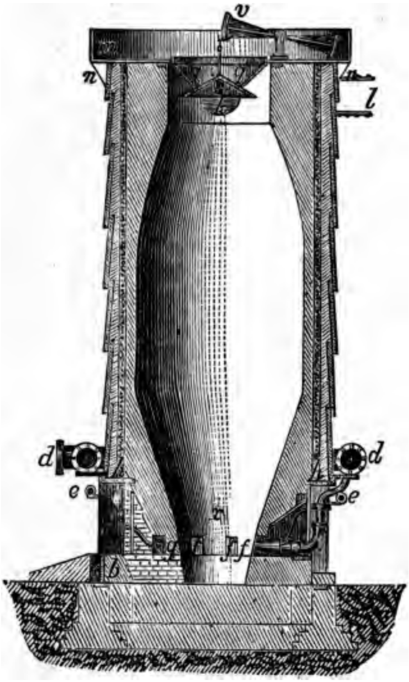

Fig. 20.—STAFFORDSHIRE BLAST FURNACE. Vertical Section through the Tymp.

showing the general arrangement of the more recent Staffordshire and South Wales furnaces, in which the *stack* is cylindrical or slightly conical, coated externally with wrought-iron plates riveted together, and fitted with the *cup and cone* arrangement for introducing the charge of ore, flux, and fuel;

b is the *dam*, and *c* the cast-iron *dam-plate* ; *d* is the *blast-main*, from which pipes descend to each of the five *twyers* employed in this furnace, and *e* is a small *water main* supplying water to the water twyers *f*, *f*, *f* ; *g* is the *water tymp* with its coil of pipes, as already described, for keeping this part of the furnace cool, and so affording protection against the action of the fluid slags at the high temperature existing in this part of the furnace. The *stack* or cylindrical part of the furnace above the *hearth* *x*, is carried upon the iron ring *h*, *h*, supported upon cast-iron pillars; and the waste gases are collected or drawn off through the opening *k* into the pipe *l*, which distributes them to the hot-blast stoves; *m* is a gallery around the *throat* of the furnace, supported upon cast-iron brackets, *n*, *n*, from its sides, upon which is landed or received the materials to be introduced into the furnace. At the sides of the hearth are placed vertical racks, which serve as supports and points of resistance to the bars used in cleaning out the hearth of the furnace. The cup and cone arrangement, as well as the mechanism employed in raising and lowering the cone, are shown, and will be subsequently described.

In a blast furnace recently erected at Middlesbrough * (with the top closed by the cup and cone or bell arrangement, to be subsequently described), the foundation was of brickwork, resting on clay; on this a circular base of solid brickwork 7 feet in diameter was erected, having a stone curb, on which rested the columns, 18 feet 6 inches high, which carried the upper part of the furnace, the lower part being supported partly by a wrought-iron conical case, and partly by the brickwork and stanchions which surrounded the hearth. From the twyers upwards, the furnace was cased with wrought-iron plates, from $\frac{3}{8}$ to $\frac{1}{2}$ inch in thickness. The interior was lined with fire-brick lumps 5 inches thick, backed with ordinary fire-bricks. The lumps forming the bottom of the hearth, which was 4 feet 6 inches in thickness, consisted of two courses, set on edge and breaking joint. These lumps, as well as those forming the lining to within a short distance above the twyers, were chisel-dressed on both faces and joints, and made to the curve of the section at each course. The principal dimensions of the furnace are: diameter of hearth, 8 feet; diameter at the bosh, 28 feet; total height from hearth to platform, 85 feet; depth of hearth at twyers (four in number), 3 feet 6 inches; diameter of bell opening, 13 feet; and cubical capacity, 30,085 feet. The ore to be smelted in this furnace is the argillaceous ironstone from the lias formation, yielding, after calcination, from 37 per cent. to 40 per cent. of metallic iron. The fuel is hard Durham coke, and the flux principally mountain limestone. The furnace is worked with hot blast at a temperature of about 1100° F., with a pressure of 3¾ lbs., and the product is stated to be from 490 to 500 tons of pig-iron per week.

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* Proceedings of the Institution of Civil Engineers.

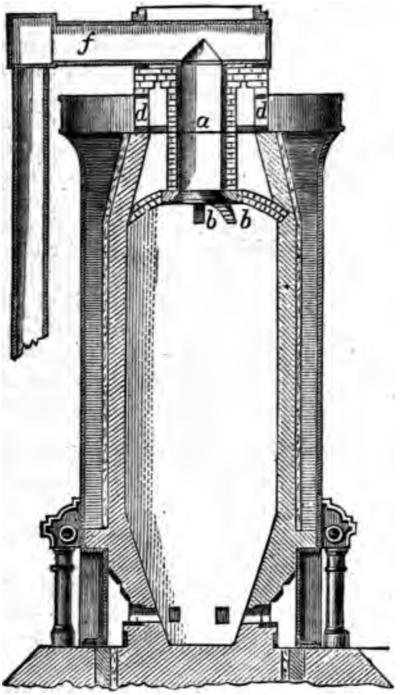

Fig. 21.—Sectional Elevation of Cupola Blast Furnace.

A well built blast furnace will often last five years without requiring to be blown out for repairs.

The blast furnaces employed at Barrow, Ulverstone, and other hæmatite districts of Lancashire and Cumberland, are of the *cupola* type, represented in fig. 21; those recently erected at Barrow-in-Furness being 62 feet in height, and 21 feet in diameter at the boshes, working with closed tops; while those previously in use were a little less in capacity, and the waste gases were only partially collected by a tube *a* suspended in the centre of the throat, and supported on six ribs of brickwork, as shown. The blast for these newer furnaces is heated to about 649°C. (1200°F.) by passing it through the hot blast stoves introduced by Mr. Gjer, and it is delivered to the furnace through seven 4-inch twyers, at a pressure of about 4¾ lbs. per square inch. Such a furnace charged with *raw red hæmatite, limestone flux,* and using *coke* as fuel, affords a *make* of 700 tons of pig-iron per week. The stack of the furnace illustrated, has an internal fire-brick lining 18 inches in thickness, between which and the outer casing of ordinary brick, is a space which is filled with sand, and the whole is enclosed in an outer casing of wrought-iron plates riveted together.

The *Blauofen,* or charcoal blast furnaces of Styria, differ from those adopted in this country, particularly in the absence of a *fore-hearth,* and in the smallness of the throat. The furnace is formed of two truncated cones, the junction of their widest parts forming the boshes, whilst the front of the hearth is stopped by a stone, in which are openings for tapping out at short intervals the metal and slag, either together or separately; for the pig-iron and slag both collect in the hearth until tapped out. These furnaces smelt spathic ores, poor in manganese, along with brown hæmatite and mixed with 10 per cent of clay, and the charge consisting of these ores passes from the throat to the hearth of the furnace in from 4½ to 5 hours.

136. Charges of Furnaces, etc.—In the Siegen district, in furnaces producing speigeleisen, a charge of 45 cwts. consists of about 29 cwt. of roasted spathic ores, 7 cwts of raw brown hæmatite, with 9 cwt. of raw limestone as the flux, and requires about 1 ton of coke for its reduction.

In South Staffordshire the average charge consists of 48 cwt. of calcined clay ironstone from the coal measures, and 12 cwt. of silurian or carboniferous limestone, per ton of pig-iron produced. Such charges when smelted with blast heated to a temperature of 750°C. (1422°F.) in furnaces of 24,000 feet capacity, require about 20 cwt. of coke per ton of pig-iron produced.

The average mixture for the production of a ton of pig-iron in the Cleveland district consists* of 46 cwt. of the calcined argillaceous carbonate of iron, known as the Cleveland iron-stone, with 11 cwt. of limestone and 21 cwt. of hard Durham coke, the furnace working with blast at a pressure of 3¾ lbs., and a temperature of 1100°F. (593°C.).

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*Proceedings of Inst. Civil Engineers.

At Dowlais, and other works of South Wales, the descent of the charge from the mouth to the hearth of the furnace occupies from 35 to 40 hours; while in Scotch furnaces, smelting blackband ironstone, in certain cases, the charge does not reach the furnace hearth under 2½ or 3 days after charging.

137. **Furnace Tops.**—For the purpose of collecting more or less perfectly the waste gases escaping from the top of the blast furnace, in order to utilise or absorb the heat due to their high temperature, as also that which they are capable of generating by their perfect combustion, in the heating of the blast, coking coal, raising steam, etc., various methods have been adopted for both open, closed, and partially closed topped furnaces.

In reference to open topped furnaces, the simplest and most durable form is a method adopted for charcoal furnaces in the Upper Hartz and elsewhere, in which an annular space is formed in the masonry of the upper end of the stack of the furnace, communicating with the interior of the furnace beneath the surface of the charge by a number of openings or channels inclining upwards to prevent the lodgment of the charge in them; a large pipe opens into the annular space, and is connected with a high stack for the production of the necessary draught to draw off the gases through this channel. In another arrangement a wrought-iron cylinder, of from 4 to 7 feet in length, is suspended in the mouth of the furnace, or a brick tube is built in the throat, and supported at its base upon arms of brickwork from the sides of the furnace, thus leaving a space between the outside circumference of the tube and the inner surface or lining of the furnace, in which space the gases accumulate and are led off by a pipe opening into it, connected as before with a stack giving the required draught for exhausting or drawing the gases in this direction. Instead of diminishing the furnace mouth by the introduction of this tube, sometimes the top of the furnace is increased in size, so as to receive the tube, when the inside of the cylinder is made of the same diameter as the top of the furnace, a space being left between its outer periphery and the mass of brickwork of the furnace, which space is connected with a tube and stack for taking off the gases. In these arrangements the gases are withdrawn from the *circumference* of the furnace, and only a portion of them are collected, a certain volume escaping and burning at the open mouth of the furnace.

In the cupola blast furnaces used in smelting hæmatite, illustrated in fig. 21 p. 119, the top of the furnace is only partially closed, and the gases, which are only partially withdrawn, are taken from the *centre* of the throat of the furnace, for which purpose a tube *a* is inserted in the middle of the throat, resting at its lower end on arched ribs of brickwork *bb* springing from the lining of the furnace. An annulus is thus formed around the tube between it and the upper course of masonry or *ring-wall* of the furnace, which space communicates by a number of openings *d d* with the gallery or platform at which the charging material is delivered, and through which the charge is introduced into the furnace. The tube *a* communicates with the cross tube *f*, by which the gases are conducted to the boilers for raising steam, to which purpose they are here wholly applied. The withdrawal of the gases through *a* is assisted by an exhausting fan.

Of arrangements which necessitate the *closure of the throat* of the furnace, and in which the whole of the gases are collected, the most prevalent is some form of the *cup and cone* arrangement, illustrated in fig. 20, page 117, consisting of a cast-iron cup, funnel, or frustum of a cone *q*, fixed to the top of the furnace, the lower opening being about one-half of the diameter of the furnace at that point. Beneath the cup is a cast-iron cone *s*, suspended from its apex by a chain or other attachment from a counterpoised lever *v*, which can be elevated or depressed about a fixed centre by gearing, or by a system of levers acting on its free end, whereby the cone *s* can be raised or lowered; *k* is a pipe opening into the furnace, leading the gases from the throat of the furnace to the hot blast stoves, boilers, etc. where they are consumed, and their calorific power utilized. This method of withdrawing the gases affords also a convenient method of charging the furnace, the charge of ore, fuel, and fluxes being placed in the cavity or hopper *q* formed by the cup arrangement when the cone is raised against its seat, and the charge is allowed to fall at the desired period by lowering the cone *s*, its form assisting in the better distribution of the charge over the surface of the materials already in the furnace, the larger pieces of fuel, etc., rolling towards the centre, while the smaller portions remain at the circumference. In this arrangement the mouth of the furnace is only opened to the atmosphere during the short interval in which the cone *s* is lowered for the introduction of the charging materials.

In order to economise the space required in the top of the furnace for the downward movement of the cone *s* in charging the furnace, it has been proposed to fix *s* in the throat of the furnace, and substitute for the cup *q* a movable cylinder of cast-iron, which could be drawn upwards so as to allow the charge to fall into the furnace; but arrangements of this class do not perform the part of distributor of the charge as efficiently as the cup and cone arrangement, and have accordingly been discontinued.

In Langen's arrangement, erected at Hörde and Siegburg, in Prussia, the mechanism is wholly external to the furnace, and, while closing the mouth of the furnace, it withdraws the gases from the *centre* of the throat instead of from the sides, as in the previously described arrangements. This apparatus consists of a bell suspended above the throat of the furnace, from the extremity of a lever, by which it can be raised or lowered, for the introduction of the furnace charge after the manner of the cylinder already mentioned, the bell sliding telescopically on the outside of the vertical gas tube, the several joints being kept tight by water, which requires to be added at intervals to supply the loss by evaporation, and the top of the tube is supplied with a safety valve to prevent explosions.

138. Blast-main, Twyers, etc.—The blast from the blowing engines is distributed around the blast furnace in a pipe *d*, fig. 20, p. 117, called the *blast-main*, situate in the more modern furnaces at some distance above the level of the ground, and supported from the columns or pillars carrying the stack of the furnace. In the older form of furnace, where the stack is carried upon four huge columns of masonry, an arched annulus was built in the base of the masonry for the reception of this pipe or blast-main. A pipe called the *goose-neck* passes vertically from the blast-main opposite each twyer opening, where it is connected by an elbow-piece with a horizontal pipe, to the end of which is attached the *blast nozzle* or *blowpipe*, which is received by the twyer proper. The bend or elbow usually contains an opening closed by a glass or mica plate, to enable the workman to see into the hearth of the furnace, the bright spot thus seen being called the furnace *eye*.

The blast is controlled by a stop valve on the main near the hot blast stove, or blowing engines, in addition to which each twyer has its own valve for the regulation of the blast. In cold blast furnaces the twyer is made of iron or copper, into which the blowpipe is loosely inserted or connected to it by a flexible leather tube; but in hot blast furnaces, owing to the increased pressure and higher temperature employed, these connections are inadmissible. The twyer, as represented in section in the accompanying figure, known as the Staffordshire twyer, consists of a hollow truncated cone of wrought-iron, with double walls, leaving a clear space between the two for the circulation of a current of cold water, introduced and withdrawn by the two pipes shown. In the Scotch twyer, a spiral of wrought-iron is enclosed in a cast-iron casing, through which the water circulates. *Bronze* and an alloy containing phosphorus, known as *phosphor bronze*, have been used for twyers with reported success, as not being so readily acted upon by the masses of metal which occasionally attach themselves to the twyers.

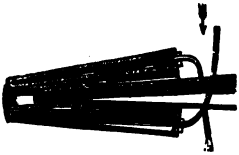
Fig. 22.—Hot Blast Twyer.

The horizontal pipe connecting the water twyers with the goose-neck, or vertical pipe from the blast-main, consists of two portions: the extremity or *blowpipe* end, formed of sheet-iron, is inserted loosely in the conical twyer, the space around it being plugged up with clay; its other end is connected by a ball and socket joint with a telescopic pipe, the latter actuated by a screw, or rack and pinion, whereby the blowpipe can be inserted or readily withdrawn for the removal of a leaky twyer, or other purpose; while the ball and socket joint allows of an adjustment of the direction of the blast, according as it is desirable to direct it upwards, downwards, horizontal, or in a lateral direction. It is often desirable, for instance, when the produce is forge pig, to direct the blast horizontally, or slightly downwards, whereby a partial decarburization of the melted pig metal may be effected, attended also with the partial removal of the sulphur, phosphorus, arsenic, etc., from the pig-iron. And when smelting refractory ores, or producing grey pig-iron, an upward inclination of the twyer is found advantageous.

The number (rarely exceeding seven) and size of the twyers depends upon the capacity of the furnace and the amount of blast to be introduced, as required for the different classes of ore treated and the iron obtained. Too much blast is attended with an increased consumption of fuel per ton of metal produced, also the reduction is effected too rapidly, insufficient time being allowed for the recarburization of the reduced iron; also the slags are cooled, and more or less solidified. On the other hand, an insufficiency of blast is attended with a loss of heat in the furnace, and the *make* (yield) of iron is diminished. The production of carbonic anhydride, with its attendant maximum of heat, extends but a short distance from the vicinity of the twyers, and, therefore, by arranging the twyers uniformly around the furnace, the combustion and heat generated are more perfectly distributed over the hearth than by passing the whole of the blast through one or two points. If one twyer only be used, it is the practice to place it in one side of the furnace, a little nearer the back than the front, the tymp being considered the front side; where two are employed, as in small charcoal furnaces, they are placed in the sides opposite each other; and if a third be added, it is placed at the back opposite the tymp; while, if a larger number are required, they are either placed in groups in each of the twyer arches, as two in the back wall, with one at each side, or two or more at each side, with one or more at the back; or as in cupola, and other furnaces, with circular hearths, the twyers are usually distributed at equal distances around the circumference.

139. Lifts.—For the purpose of raising the materials of the charge to the furnace mouth, except in hilly countries, where the mine is above the level of the summit of the furnace, and the materials can be run directly from the mine to the charging gallery, *lifts* or elevators of various types are employed. Amongst the older forms still employed is the inclined plane, fig. 23, an arrangement consisting of an inclined tramway between the ground and the top of the furnace, inclined to the horizontal at an angle of 25° or 30°; it is formed of a pair of girders, braced together, and supported by one or more pillars, or upon trestle work, between the foot of the plane and the platform at the mouth of the furnace; on this incline is placed a platform carriage, A, triangular in vertical elevation, with two pairs of wheels of unequal size, as shown. The platform or table of the carriage is always horizontal as it moves up and down the inclines, and when at the foot of the plane, the table is level with the surface, so that the barrows can be run directly on to it, the table being large enough to hold four or more of the wheel-barrows employed for charging; also, when the carriage arrives at the top of the incline, the table is then level with the charging platform of the furnace, and the barrows can be moved directly off the carriage on to the platform or gallery. At the Barrow Iron Works, two of these inclines are placed side by side, the carriages being connected together by a chain passing round a drum, so that as the one ascends, the other is descending, the necessary power being obtained from a small engine on the surface driving the winding apparatus. At these works, two planes are sufficient for the supply of

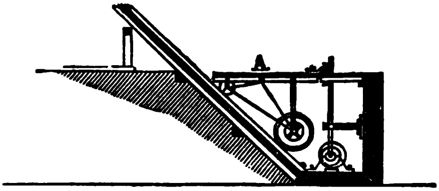

FIG. 23.—INCLINED PLANE, for elevating the charge to the furnace mouth.

seven furnaces, or for raising about 8000 tons of ore, and other materials per week.

The inclined planes, Jacob's ladder, and other forms of lift, have generally given place to some form of vertical lift, actuated either by steam, compressed air, or hydraulic pressure. When steam is employed direct, the material to be raised is placed in a cage, or placed on a platform, moving between vertical guides, and connected with a piston actuated by the steam pressure. Of hydraulic lifts, amongst the most perfect are those constructed upon Sir W. Armstrong's principle, in which the platform is connected to a chain which passes over a system of pulleys before it is attached to the ram which is actuated by the hydraulic pressure. According to the multiplication of the lengths of chain by the system of pulleys employed, the table is raised to a more or less considerable distance for a short movement of the ram; in this manner a movement of 5 or 6 feet in the ram, actuated by hydraulic pressure from any source, communicates to the lift an elevation of 30 or 40 feet, or more.

Of the numerous pneumatic lifts, the one most extensively adopted in the more modern of the Cleveland furnaces is that of Mr. Gjers, in which a large cast-iron piston or ram, to which the table or lift is connected by means of wire ropes passing over large pulleys, and attached to each corner of the lift, works in a cylinder, some 36 inches in diameter. The weight of the piston is adjusted so as to exceed the weight of the empty platform by an amount, say, of one ton, while the platform, when loaded, is heavier than the piston by the same amount; hence, on applying beneath the piston a pressure of 3 or 4 lbs. above the atmosphere, it rises, and the table is brought down, while a similar exhaustion or vacuum produced beneath the piston causes it to descend, and the loaded platform to ascend. The necessary pneumatic pressure or vacuum is obtained from a small engine working pumps, which, by altering the position of a reversing lever, act either as exhausting or forcing pumps.

140. Blowing Engines.—The engines for supplying to each large furnace 50,000 or 60,000 cubic feet of air per minute, in a constant and regular stream under a pressure of from 3½ to 7 lbs. per square inch, are necessarily of large dimensions and power, and whether horizontal, vertical, or beam engines be adopted, cast-iron *blowing cylinders* are now generally employed in lieu of the fans, bellows, blowing chests, etc., originally used. The steam cylinders are often 45 inches in diameter, whilst for the same engines the blowing cylinders are from 80 to 100 or 110 inches in diameter, and are fitted with solid pistons. The valves fitted to each end of the blowing cylinders for the admission of air to the cylinder and delivery of the same to the blast main, are either of the slide or piston type placed outside the cylinder, or they are flap or disc valves of leather or india-rubber fitted into the cylinder covers. Thus as the engine makes its stroke the air in front of the piston is driven under the required pressure through the delivery valve into the blast main, whilst the admission valves at the opposite end of the cylinder are at the same time opened to the atmosphere; and a cylinder full of air is thus delivered to the blast main at both the forward and back strokes of the engine, whereby a continuous stream of blast is maintained between the engine and the blast furnace.

To avoid the fluctuations, irregularities, and intermittent action of the blast, that would occur from an injection of the blast direct from the engine to the furnace, a *regulator* is inserted in the course of the main, between the engine and the furnaces; this is merely a reservoir of iron, or occasionally of masonry lined with cement, of a capacity equal to from 20 to 50 times the volume of blast delivered per second, and provided with a manhole and safety valve. In this manner the blast is delivered in a continuous stream. If the main or pipes between the engine and the furnaces are of considerable length, the regulator becomes unnecessary, the volume of air contained in the pipes serving the same purpose.

141. Rachette Furnace. — The Rachette furnace has a shaft *a* about 30 feet in height, rectangular (oblong) in all horizontal sections, and gradually increasing in width from the hearth to the mouth, which is about two and a half times the width of the hearth; the twyers, from twelve to sixteen in number, supplied from the blast-mains *f*, *f* are arranged in two rows in the long sides of the furnace, not opposite each other, but so that the nozzles on the one side direct the blast against the space between the twyers of the opposite side, and so distribute the blast more uniformly over the area of the hearth; or, instead of separate twyers, one long twyer, with a horizontal slit in the direction of its length, distributing the blast in one continuous sheet of air, has been tried.

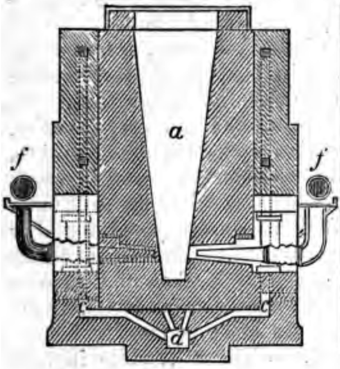

Fig. 24.—Vertical Section of Rachette Furnace.

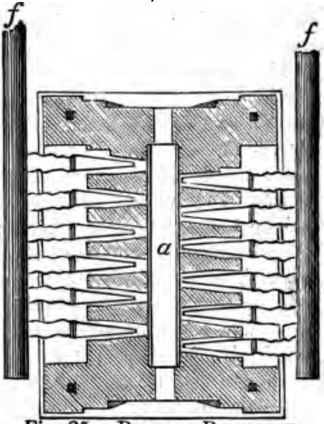

Fig. 25.—Plan of Rachette Furnace.

The two ends or fore-hearths are exactly alike, allowing the metal and slag to be tapped from either end. In the walls are left a number of channels *c,c* communicating with one another, and with similar passages and a chamber *d* placed in the masonry beneath the hearth; these passages have a threefold object: they serve to heat the masonry more quickly and uniformly, when the furnace is first lighted or *blown-in*, by circulating, through the walls of the furnace, the gases from a fire made in the chamber *d*; and during the working of the furnace cold air circulates through them, cooling the mass of masonry, especially of the hearth, and lessening the transmission of heat from the furnace to the exterior; lastly, they lessen the cost of the furnace by reducing the quantity of materials employed in its erection. An economy in fuel is claimed for this furnace, due to the longer time during which the smelting materials are exposed to the ascending gases, due to the diminished velocity of the latter from the increasing section of the furnace towards the mouth, with a consequent reduction of the temperature and diminution in the loss of heat carried away in the escaping gases.

In the Ural districts of Russia, where these furnaces were first erected, they were worked with cold blast and charcoal fuel, smelting magnetic iron ores, when the produce of grey pig-iron was 30 tons per day of twenty-four hours.

142. Hot Blast.—The use of the hot blast, patented by Neilson in 1828, was first used in the Clyde Iron Works, and its use at the Blythe Iron Works was attended, in 1831, by the substitution in the blast furnace of raw coal for coke, and so rapid was its general adoption that, with one exception, it was in universal application throughout Scotland in 1835.

The temperature to which the blast is raised depends upon the *nature* and *quality* of the fuel and ore employed, together with the kind of pig-iron to be produced. Charcoal, as being less dense, and more readily combustible, does not require the blast to be heated so high as where coke is the fuel; accordingly, in charcoal furnaces, the blast is usually heated from 100°C. to 300°C. (212°F. to 572°F.), while in coal and coke furnaces the temperature employed rises as high as 800°C. (about 1477°F.), but the temperatures most generally in use range from 600°C. to 700°C. (1100°F. to 1300°F.).

With the use of the hot blast, the combustion of the fuel commences much lower down in the furnace, the zone of reduction in the furnace is carried through a greater vertical distance, and there is a considerable increase of the temperature in the vicinity of the twyers as compared with the same furnace working under cold blast; for the injection of cold air is attended with a very considerable absorption of heat in the vicinity of the twyers, due to the expansion of the air by the heat of the furnace. The higher initial temperature of the hot blast, together with the more rapid combustion of the fuel effected by it, and the conversion of the carbon of the fuel into carbonic anhydride, causes the calorific intensity of this zone to be much increased, which increase in the temperature first necessitated the use of water twyers for hot blast furnaces. The effect of the introduction of the hot blast is a very considerable economy in the item of fuel. Percy states that at the Clyde Iron Works in 1829, when cold blast was used, the average consumption of coal used as coke was 8 tons 1 cwt. 1 qr. per ton of pig-iron produced, while in 1833, at the same works, when using hot blast, heated to 300°F. (149 ° C.), the average consumption of coal was reduced to 5 tons 3 cwt. 1 qr. per ton; but in 1883 furnaces in the north using blast at a pressure of 4 lbs. and heated to a temperature of 900°F. (538°C.) were making iron with a consumption of 2 tons of hard splint coal to the ton of iron made. Dr. Percy also gives the estimated amount of charcoal used in the Swedish furnaces employing blast heated to 350°C. (662°F.), and producing grey iron from lake and bog ores, to be 67 per cent. of that required for similar furnaces working with cold blast.

The advantages of the hot blast, then, are chiefly the *saving* in fuel, with the increased *make* of the furnace. The former economy arising, as already noted, from the higher temperature of the zone near the twyers, consequent upon the more rapid combustion of the fuel when burnt by heated in lieu of cold air, whereby the zone of active combustion or greatest heat is brought to a lower level in the furnace, attended with the reduction of the metal at a greater depth from the mouth than occurs under cold blast, and in this manner allowing of the use of raw coal instead of coke; while from the enlarged hearth, with a better distribution of the heat over it, and the *heavier burdens* carried by hot blast furnaces, an increased *make* of iron is ensured. With the use of hot blast, the slags require to be more basic than in cold blast furnaces for the production of the same pig-iron, since, owing to the increased temperature produced by the hot blast, an increased amount of silicon will be reduced and pass into the pig-iron, with a deterioration of its quality as a foundry pig, unless its reduction be to a certain extent prevented by the addition to the charge of a larger proportion of lime, thereby rendering the slag more basic.

143. Blast Ovens, etc.—The apparatus employed for heating the blast, known as *hot blast ovens* or *stoves*, consist usually of a series of tubes of various forms, connected at one extremity with the cold air, and at the other with the hot blast-main; they are arranged in a chamber of fire-brick, and are heated externally, either by an independent fire made beneath, or more generally by the combustion of the waste gases collected from the mouth of the blast furnaces, which are burned in these stoves, so that the flame and gases play around the outside of the pipes before they escape to the atmosphere. The stoves heated by the last method are more durable than if heated by coal burnt on an independent grate. More recent are the stoves of Mr. Cowper and of Mr. Whitwell, erected upon the regenerative principle of Mr. Siemens, in the use of which a large saving in fuel is effected.

The older form of stove consisted of a chamber containing a series of arched pipes of cast-iron, the feet of which were received in sockets connected with two mains placed along the sides of the chamber in the direction of its length, one of which was the cold and the other the hot blast-main. The arched pipes were at first made circular in section, but to increase their heating surface, oval or elliptical and square sections have since been employed. This stove, when heated by fuel direct, has an oblong fireplace along its whole length; but, as is now more usual, the gases from the blast furnace are introduced at one end, and air is admitted for their combustion through the bars of a grate placed at the same end. From eight to twelve pipes are thus placed in one chamber, which has a partition across the middle of its length, reaching nearly to the roof, and thus dividing the larger chamber into two shorter ones, so that the gases or flame, after circulating around the pipes in the one, pass over into the other, and heat the pipes contained therein before escaping to the chimney or stack. To obtain a better circulation of the air through the pipes, *stops* have been introduced into the mains, so that the blast ascends the arched tube from one main and descends to the opposite one; then returns back to the first main by the next pipe, and so on, so that the blast, before making its exit, circulates from one side of the oven to the other repeatedly in its course through the stove. In this form of stove the unequal expansion of the pipes, with their extremities fixed to the mains, leads to very frequent breakages, to obviate which one of the mains has been placed on rollers, allowing it an inward or an outward motion, as required by the expansion of the arched pipes.

In what is known as the *pistol pipe* modification (fig. 26), from a supposed resemblance in the form of the pipe to the shape of a pistol, the pipes *a* are arranged along the two sides of the median line or fireplace *b*, if the stove be heated by such; the pipes of the two sides are not, however, connected by an arch, as in the last case, but the closed end of each pipe is turned slightly over and may rest against the opposite pipe, which thus support each other without being directly connected. Each pipe is divided by a septum or partition,

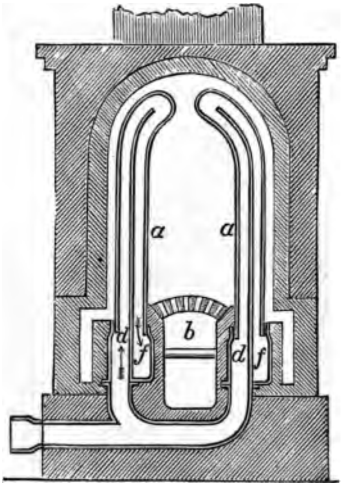

Fig. 26.—Pistol-pipe Hot Blast Stove.

reaching nearly to the closed end, and connected at its foot with a corresponding division in the main, so that the cold blast from the intake *d, d* ascends the pipe and returns down the same pipe, but on the opposite side of the septum, as indicated by the direction of the arrows, to the exit side *f* of the main, which is connected with the furnace. This form of stove is used in Scotland, Cleveland, and other districts of England, as also in France and Germany.

In the round and oval ovens used in Lancashire and Staffordshire, the two mains, running the length of the stove in the previous cases, are replaced by a cast-iron circular or oval ring, trapezoidal in section, and divided by a partition into two compartments, or an inner and an outer annulus, one of which serves as the cold and the other as the hot blast-main; the two pipes or channels so formed receive the lower ends of the vertical heating pipes, which are placed close together in pairs all round the stove, the upper extremity of each pair being joined by a short horizontal pipe; the fireplace is placed in the centre, the flame and products of combustion making their exit through flues in the dome surmounting the heating chamber or oven.

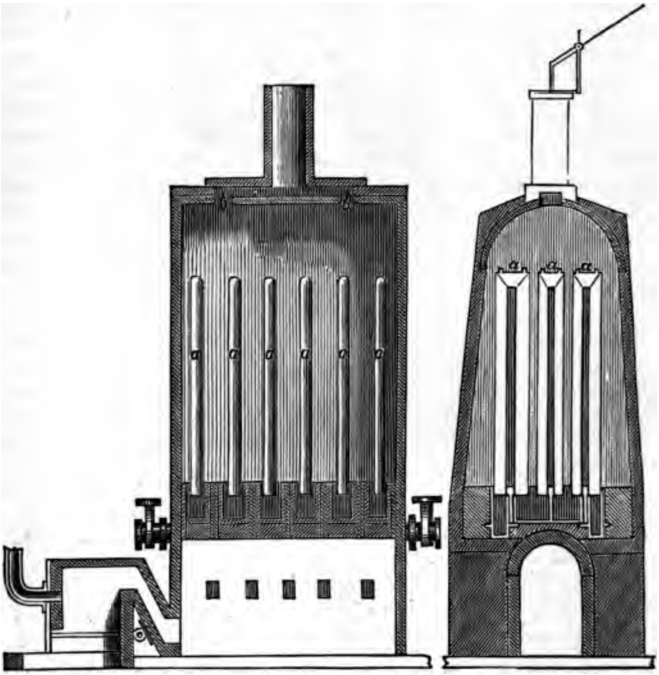

Fig. 27.—*Longitudinal Vertical Section.* Fig. 28.—*Transverse Section.*

Hot Blast Stove.

Other stoves in use in Lancashire, Staffordshire, etc., are rectangular in form (figs. 27 and 28), and have two mains running along the sides for the length of the stove, which serve as inlet for the cold air and outlet for the heated blast respectively; these pipes or channels receive the lower end of one limb of each of the vertical heating pipes *a*, *a*, of which there are six rows of three pipes each, in each stove, and the cold air entering at one end of the oven ascends one limb and descends through the other limb of each of these pipes before it passes out of the stove to the hot blast-main. The stove is heated as before, either by its own fire or by the gases of the blast furnace, introduced into a chamber beneath the pipes, and burnt in the space surrounding them, the flame and products of combustion making their exit through flues *b*, *b*, in the dome surmounting the heating chamber or oven.

The loss and difficulties arising from the fracture, rapid corrosion, and oxidation of the iron pipes when very high temperatures are employed, have led to the introduction of stoves on the Siemens' "regenerator" principle. The mass of brickwork forming the regenerator or stove is heated either by its own direct fire, or by the sensible heat, and the heat generated by the combustion of the waste gases of the blast furnace.

144. Cowper's Stoves.—The hot-blast stove introduced by Mr. Cowper acts upon the principle of the Siemens' regenerator, in which fire-brick heating surfaces are substituted for the cast-iron tubes, detailed in the previously described stoves. The brick permits of a much higher temperature being imparted to the blast than is practicable in stoves of which cast-iron is the heating surface, and by their use a correspondingly large increase occurs in the yield of the blast furnace. In the earlier forms of this stove, introduced at Ormesby, near Middlesborough, the fire-brick chambers were heated by a fire maintained below them; but the present practice is to heat the stoves by the combustion within them of the waste gases of the blast furnace. For heating the blast continuously, a pair of stoves is necessary, the blast being turned alternately through each at intervals of about one and a half hours. As applied for utilising the blast furnace gases, the stoves consist of cylindrical chambers of fire-brick, closed at the top, and cased with wrought-iron plates. A vertical shaft is formed towards one side of the stove, and reaches almost to the roof; in the space around this, and between it and the walls of the stove, is built a chequer work of fire-brick, arranged so as to leave rectangular spaces between and amongst the bricks, for the passage of the heated gases and cold air alternately. At the lower end of the vertical shaft are suitable valves which connect the stove with pipes for conveying the furnace gases and air for their combustion to the stove; whilst another valve connects the stove with a flue from the stack which produces the necessary draught. On closing these valves communication can be opened between the stove and the exit pipe, or pipes, leading the heated air to the blast furnace. In this manner the combustion of the gases is effected at the top of the stove, and the flame, with the heated gases, is drawn down through the channels amongst the bricks, and escapes to the stack at a comparatively low temperature, while the mass of brickwork, after from one and a half to two hours, will have attained to a uniform strong red heat. The gases are now turned off, communication with the chimney closed, and at the same time the other valves are opened, by which cold air is drawn in at the bottom and passed upwards from the colder to the hotter part of the stove, reabsorbing in its passage the heat previously imparted to the fire-bricks. The temperature of the air in this manner is raised to 700° C. or 800° C. before being driven into the blast furnace. Meanwhile, another stove has been heated in the manner first described, and, after one and a half hours, the course of the gas is again reversed, and the first chamber is reheated while the second chamber is heating the blast, and so on.

The Cowper hot-blast stoves recently erected have been much increased in size over those erected during the earlier years of their use, and they now reach to 50 and 55 feet in height by 20 and 25 feet in diameter. Their construction has also been modified so as to facilitate the cleaning out of the dust, etc., which accumulates in the flues and in the fire-brick chequer work. With either the Cowper or the Whitwell stoves to be subsequently described, the highest temperatures required by modern blast-furnace practice, even such as are necessary for the production of speigeleisen and of ferromanganese are readily attained, whilst the difference in temperature observed when the current of blast is turned from the one stove to the other is confined within very narrow limits, and is not sufficient to affect the working of the blast-furnace.

The most recent Cowper stoves, figs. 29, 30, consist of* an outer wrought-iron casing, lined internally with several rings of fire-brick work, the stove being closed by a dome-shaped roof also lined with fire-brick. The circular flame flue *m*, instead of being central as at first constructed, is built so as to touch the fire-brick lining at one side, and at its base are the inlet valves G for the gases from the blast-furnace, and the valve A for admitting the air necessary for the combustion of those gases, whilst at H is placed the outlet valve for the hot-blast.

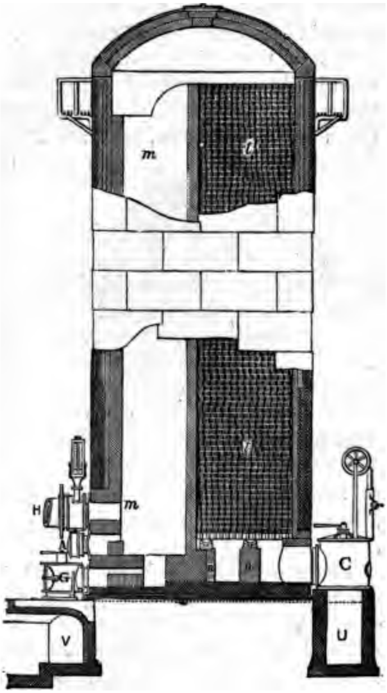

Fig. 29.—PART SECTIONAL ELEVATION OF THE COWPER HOT-BLAST STOVE.

The body of the stove, as shown by fig. 29, is thus largely occupied by the fire-brick chequer work or regenerators *t*, at the base of which are the cold-blast valve B and the chimney valve C, whilst at D and D are the cleaning doors. Built at intervals over the bottom of the stove are dwarf pillars *n* of brick-work, which carry short girders, upon which rest a series of strong girds P, fig. 30, for carrying the regenerators or chequer work of fire-brick. The bricks in the regenerators are now made smaller than formerly, and are arranged so as to leave vertical open passages of about 4 inches square from the girds at the bottom to within a few feet of the domed top of the stove.

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* Author's *Steel and Iron*, p. 151.

When the chimney-valve C, fig. 29, is open, gas and air are also being admitted at the bottom of the flame flue *m*, through the gas and air valves G and A respectively. The gases at once ignite, and an immense flame, split up into three currents by the partitions shown in the plan, fig. 30, ascends through the flame-flue *m*, and spreads out beneath the roof over the top of the regenerators, from whence the incandescent products of combustion are drawn downwards through the numerous passages of the chequer work towards the chimney flue C, thus heating the chequer work to a very high temperature before the gases finally escape by the chimney at a temperature of only about 240° C. (400° F.).

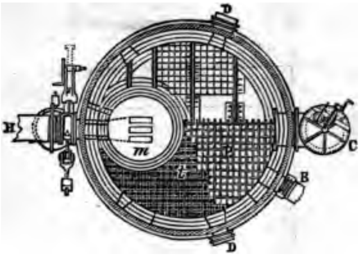

Fig. 30.—Sectional Plan of the Cowper Hot-blast Stove.

The stove having been heated in the above manner, the *gas-valve* G, the *air-valve* A, and the *chimney-valve* C are all closed, while the *cold-blast valve* B, fig. 30, and the *hot-blast valve* H are opened, whereupon the blast from the engine enters the stove at B and ascends through the numerous small passages of the regenerators to the full height of the stove, and then descends through the flame-flue *m* to the hot-blast valve H, through which it is driven to the blast main, and so to the furnace twyers. In this manner the blast circulates through the stove in exactly the reverse direction to that traversed by the gases when heating up the stove, and the cold-blast absorbing the heat stored up in the fire-brick regenerators is rapidly raised to a temperature of from 600° C. to 800° C. (1110° F. to 1472° F.) as may be required.

145. Whitwell Stoves.—In these stoves, as in the Cowper stoves last described, a mass of brickwork within the stove is first heated to redness by the heat developed upon the combustion within the stove of the waste gases of the blast-furnace; after which the combustible gases and air are directed into another stove, whilst the heat stored up in the brickwork of the first stove is imparted to the blast of air which is now driven through it by the blowing engines.

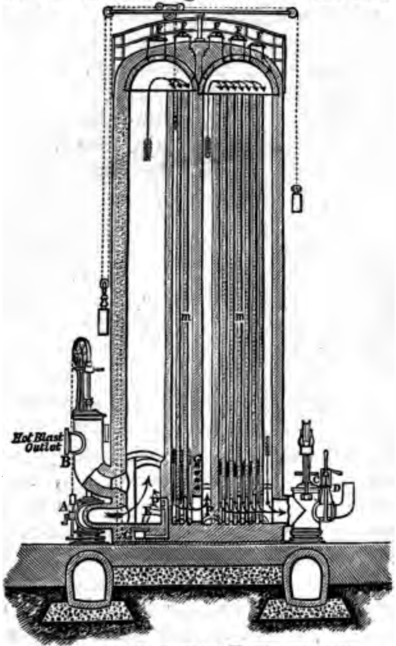

Fig. 31.—Sectional Elevation of Whitwell's Hot-blast Stove.

The principal differences between the Cowper and the Whitwell stoves consist in the arrangement of the firebricks forming the heating surfaces, and in the manner in which the combustion of the furnace gases is effected within the stove. Mr. Cowper arranges the bricks forming the body of the stove, as a chequer work in which numerous small passages are left, through which the air and gases circulate; whereas in the Whitwell arrangement, the heating surfaces consist of a number of narrow vertical flat walls or flues, *m*, figs. 31, 32. In the Cowper stove also the combustion of the gases is effected in one large flame-flue or combustion chamber *m*, fig. 29; whilst in the Whitwell arrangement the air required for the combustion of the gases is admitted at several points, and the combustion is thus only completed after the gases have partially traversed through the stove.

The Whitwell stoves are from 60 or 70 ft. in height, and from 20 to 22 ft. in diameter. They consist of a vertical cylindrical casing (fig. 31) of wrought-iron plates rivetted together, within which is built a lining of fire-bricks; but between this lining and the outer shell is left a space of about one inch, which is filled up with granulated slag. Within the cylindrical chamber are built a series of narrow vertical chambers *m*, *m*, the different rows of which communicate with each other either at the top or the bottom. Attached to the outside of the casing are cast-iron valves for regulating respectively the supply of gas, air, and blast to the stove, and for connecting the stove with the chimney, as will be immediately described. The casing, etc., of the valves for admitting the blast-furnace gases to the stove, and connecting the stove with the hot-blast main, are usually made hollow, and are cooled by the circulation of water through them. Near to the bottom of the stove are *eye-pieces*, P, P, arranged around the circumference, and through these a view of the interior is obtained so as to judge of its temperature and requirements. In the roof of the stove are apertures, F, F, closed by covers during the regular working, but movable for the introduction of long scrapers for cleaning the dust, etc., from the several flues; also at E, E, fig. 31, near the bottom are arranged six openings for cleaning out the dust, etc., collected from the flues into the bottom of the stove, and which openings are closed by movable doors as required.

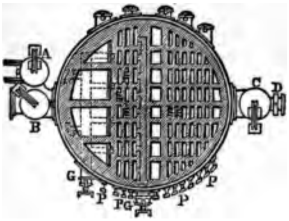

Fig. 32.—HORIZONTAL SECTION OF THE WHITWELL HOT-BLAST STOVE.

The gases from the blast-furnace enter the stove by the valve A, whilst at the same time air enters through the air-courses G, sufficient in quantity, however, only for the partial combustion of the gases. The heated gases then ascend through the vertical combustion chambers to the top of the stove, as shown by the course of the arrows, where the gases distribute themselves over the top of the flues, and descend by one or more chambers towards the bottom of the stove. Here more air is admitted, and the combustion of the gases is completed as they reascend from the bottom to the top of the stove through another wide combustion chamber. The products of combustion finally descend through the other narrow flues or chambers to the chimney valve, from which they escape to the atmosphere at a temperature of from 300° F. or 400° F. (149° C. or 204° C.).

When the fire-brick chambers of the stove have been thus sufficiently heated, the gas-valve A, the chimney-valve C, and also the air-valve are each closed, whilst the cold-blast valve D, with the hot-blast valve B, which were previously closed, are thereupon opened. The current of blast thus enters the stove at its coldest point D, near the chimney valve, and passes through the several passages towards the hotter parts of the stove exactly in the reverse direction to that pursued by the gases in heating up the stove. In this manner the blast, by passing over the heated brickwork, becomes heated before it passes out at B to the hot-blast main at a temperature of 1300° F. or 1400° F. (704° C. to 738° C.), while higher temperatures are attained according as the reversal of the valves required for heating up the stove, and for passing the blast through the same, is effected at more or less frequent intervals.

146. Flue-dust.—The white or grey dust which is carried over with the waste-gases from the blast-furnace contains about 24 per cent. of silica, existing partly in the free state, but also in combination with lime, potash, soda, and alumina. Lime forms about 26 per cent., potash about 17 per cent., soda 9·5 per cent., and alumina 10 per cent. of this dust, whilst the other constituents are magnesia, ferric oxide, manganous oxide, sulphur, carbonic anhydride, water, and cyanogen, each in smaller proportions. This dust collects with such rapidity in the chequer work of the Cowper stoves, and on the walls of the vertical cells in the Whitwell stoves, as to require removing by the cleaning of the stoves at comparatively short intervals in the manner already noted.

CHAPTER VIII.

MALLEABLE IRON.

IRON in its minimum state of carburation is designated as *malleable*, *bar*, or *wrought* iron; it then possesses a colour varying with its quality, and the mechanical treatment it has undergone, from bluish to blackish shades of grey. After melting it is decidedly crystalline or granular on fracture; but on rolling or hammering it assumes a fibrous structure, at the same time greatly increasing in tenacity. Its specific gravity ranges between 7·3 and 7·9, average specimens giving about 7·6 to 7·7; its linear and cubical expansion by heat are less than those of most metals, a bar expanding 0·000111 to 0·000126 of its length for each degree centigrade; its specific heat is 0·114, taking water as unity. The melting point of malleable iron varies with its degree of carburization: the larger the amount of carbon it contains, the lower being its melting point. Scheerer gives the melting point as 2000° C., but before fusion it passes through a soft pasty condition, in which, if two clean surfaces be brought into contact, and pressure applied, union takes place between the two, or, technically, the pieces are *welded* together, malleable iron possessing this quality of *welding* in the highest degree; at a red heat it may be hammered, forged, or rolled into any required form. The *malleability* and *ductility* of malleable iron are very considerable, increasing with the temperature to which it is heated, but these qualities are powerfully influenced by the presence of only small quantities of certain impurities; the presence of only 0·03 per cent. of *sulphur* rendering it *red-short*, that is, brittle and unforgeable while in the hot state; small quantities of *copper* also are attended with the same result; while *phosphorus*, on the other hand, renders the metal weak and brittle at ordinary temperatures, or, as it is called, *cold-short*. Eggertz states that the presence of 0·25 per cent. of phosphorus makes malleable iron sensibly cold-short. 0·35 per cent. of *silicon* in bar iron induces *cold-shortness*, at the same time lessening its tenacity. *Tin* hardens malleable iron, but at the same time renders it extremely brittle, incapable of being welded, and cold-short. *Antimony* and *arsenic* also produce a *cold-short* iron. *Titanium* present in pig-iron passes but in small quantities, if at all, into the malleable iron produced therefrom, and cannot accordingly influence its quality. *Zinc* and iron alloy well together, as in the operation of *galvanizing* iron, in which an alloy of zinc and iron (formed by the immersion of clean iron plates in melted zinc) is deposited on the surface of the plate; such galvanized plates do not so readily suffer from oxidation on exposure to moist air. Continued hammering of iron in the cold state induces hardness and brittleness, with a more or less crystalline structure in the iron. Malleable iron undergoes no change in dry air, or water free from air; but it is rapidly coated with a scale of oxide or *rust* if it be exposed to the action of moist air, the oxidation and corrosion extending quite through the mass, if a sufficient length of time be allowed (p. 19). Heated to redness, and it rapidly oxidises, ordinary *forge scale* being an oxide so formed; while if heated to whiteness in the air, it burns with the production of magnetic oxide; bar-iron so heated, in contact with air, is technically called *burnt iron*, and in this condition is very friable, is both red-short and cold-short, and incapable of being welded; these latter peculiarities of burnt iron are ascribed by some to an absence of carbon, and by others to the presence of oxide of iron in the mass. For the action of carbon, carbonic oxide, cyanogen and carbonaceous matters upon iron at a red heat, see p. 76. Malleable iron is strongly attracted by the magnet, but cannot be permanently magnetised; if heated to redness, and plunged into cold water, it is not hardened but retains its original softness; it is completely dissolved in moderately dilute acids, but very dilute hydrochloric acid leaves a carbonaceous residue. Malleable iron usually contains from 0·02 per cent. to 0·25 or 0·3 per cent. of carbon, but iron containing the latter amount of carbon is essentially steely in its character, 0·2 or 0·25 per cent. being the more usual limit to the carburization of malleable iron; the steely quality is, however, influenced by the freedom of the metal from other ingredients, especially silicon, sulphur, and phosphorus; the more free iron is from these elements, the larger is the proportion of carbon that can be combined with it without producing the steely quality. The tensile strength of malleable iron ranges from 17 to 26 tons per square inch, the average strength of the best qualities being from 23 to 24 tons per square inch, and a piece 2 inches long and ½ inch in sectional area of such metal will stretch 40 per cent. of its length before breaking. The tensile strength is very much increased by wire drawing.

ANALYSES OF MALLEABLE OR BAR IRON.

Source,	Swedish.	Shortridge and Howel.	Low Moor.	Dannemora.
Brand,	O O.	Armour Plate.	Armour Plate.	
Analyst,	*Author.*	*Percy.*	*Tookey.*	*Schafhaütl.*
Iron...............	99·853	...	99·372	98·78
Carbon............	0·075	0·230	0·016	0·84
Sulphur...........	0·032	0·190*	0·104*	..
Silicon	0·114	0·014	0·122	0·12
Phosphorus.......	0·004	0·020	0·106	...
Manganese........	Trace.	0·110	0·280	0·05
Nickel.............	...	...	Trace.	..
Cobalt.............	...	..	Trace.	...
Copper............	...	.	...	0·07
Arsenic	...	...	. .	0·02

Bar-iron of commerce is designated as *No.* 1 *iron* or *puddled bar*, *No.* 2 or *merchant iron*, and *No.* 3 or *best iron*, while further treatment of the bar yields *best best* and *treble best* iron. These grades or qualities have reference chiefly to the treatment in hammering, piling, welding, and rolling of the metal after its conversion from pig-iron to malleable iron. For No. 1 iron, the bloom of malleable iron is removed from the furnace in which it has been produced, and hammered, or squeezed, and then passed at the same heat through the series of grooves in a train of rolls, whereby it is converted into a long flat bar, usually having a rough surface, and of dimensions varying with the purpose to which it is to be applied. For the production of No. 2 or *merchant bar*, No. 1 is cut into lengths and piled into oblong rectangular masses, which are then raised to a welding heat in a reheating furnace, when the mass is hammered and re-rolled, or may be rolled without the intermediate hammering, the pressure of the rolls welding the various elements of the pile into one mass. This class of iron is the lowest that is available for smith's work. The process of cutting up, piling, reheating, and welding by rolling is repeated upon No. 2 for the production of No. 3, and so on. The size of the pile, manner of piling, and quality of irons introduced into any pile, depend upon the form and use for which it is intended. No. 3, or *best* iron, is tougher and more ductile than No. 2, and altogether better adapted to the uses of the smith; this is the quality designated in engineers' specifications as *best Staffordshire*. *Best best* is used for chains, rivets, etc.

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* Probably too high.

Malleable iron is produced either *direct* from the ores, as by Siemens' process, and the Catalan process, the latter now only practised in the Pyrenees, India, Sardinia, and some parts of America and Africa; or by the *indirect process*, in which pig-iron is treated in furnaces so as to deprive it of almost the whole of its carbon, silicon, sulphur, phosphorus, and of certain rarer metals when these chance to be present in the original pig-iron.

PRODUCTION OF MALLEABLE IRON DIRECT FROM THE ORE.

147. Siemens' Process.—This process, as also the furnace employed for the production of malleable iron direct from the ore, is described under steel, p. 210.

148. Catalan Process.—This almost extinct process is conducted in a furnace, consisting of a hearth or four-sided cavity (fig. 33), somewhat wider at the top than at the bottom; the bottom is made of some refractory stone, as sandstone, granite, porphyry, etc., and is either flat or slightly concave. The back wall through which the twyer is introduced is formed by the brickwork of the building, faced by rectangular pieces of iron *a*, *a* to the level of the twyer, above which is stonework; the opposite side is convex outwards, and is formed by pieces of iron, *b*, *b* resting against the masonry; of the two other sides, the one is formed of rough masonry, while the other, forming the front of the furnace, consists of two plates of iron, in the lower of which is made a hole for tapping out the slag from the hearth; the top edge of this plate serves also as a fulcrum for the bars employed in lifting the bloom of metal from the hearth. The twyer of sheet copper is introduced, as shown, through the side wall, the blast of cold air being maintained by a machine called a *trompe,* an apparatus consisting of two tanks, the upper one *a*, fig. 34, communicating with a copious supply of water, and connected with the lower tank or air chamber *b*, by two wooden pipes or trees *c*, *c*, provided with holes at *d*, *d*, inclined as shown; the upper ends of the pipes are opened and closed by the introduction or withdrawal of the stopper *e* from the funnel-shaped mouth formed in the top of *c*, *c*; in *b* is an opening *f* for the escape of water, while the twyer is connected by sheepskin with the pipe *s*, joined to the flattened copper tube forming the twyer. By raising *e*, the water passes down *c*, drawing the air through the oblique openings *d*, *d* along with it, the water escaping from the chamber *b* by the opening *f*, while a continuous blast of air is thus maintained through *s*; this form of blast is, however, under the disadvantage of being always highly charged with water.

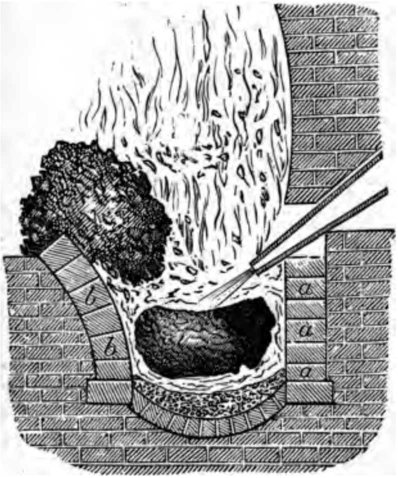

Fig. 33.—Catalan Furnace.

The twyer is usually inclined at from 30 to 40 degrees, *but this* varies with the degree of carburization it is desired to attain in the product, the less the inclination and the more slowly is the metal reduced, thus allowing a more lengthened contact of the reduced metal with the fuel, attended with a higher degree of carburization in the product, or the production of a steely iron; on the contrary, a greater inclination, promoting the rapid reduction of the iron is attended with the production of a softer metal.

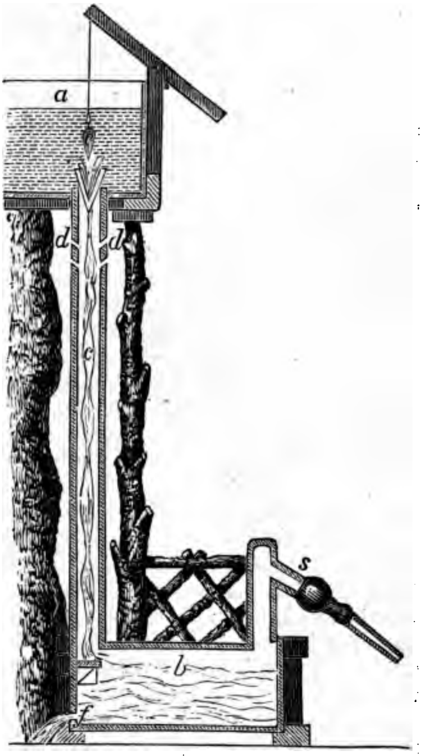

Fig. 34.—TROMPE OR BLOWING MACHINE OF THE CATALAN FURNACE.

In conducting the process, the hearth bottom, supposed to be heated from a previous charge, is covered with a coating of charcoal, and then the ore, usually an easily reducible brown hæmatite broken into small pieces, is placed against the side *b*, *b*, until the cavity is about one-third filled (if carbonates of iron be smelted, they must be first roasted or calcined), the space between this and the wall *a*, *a* is filled with charcoal; the whole is then covered with a layer of moistened charcoal dust and small ore. For the first two hours the full force of the blast is not employed, after which the blast is turned on full, and the workman pushes the descending pasty charge towards the twyer, to promote its fusion and the separation of the reduced metal from the slag; fresh quantities of small ore being continually added until the whole charge has been introduced. The metal and slag then collect in the hearth, from which the slag is tapped out at intervals through the hole in the front plate. In about 5 hours the reduction is complete, and, the blast being turned off, the spongy metal or mass of malleable iron, weighing about 3 cwt., is collected together into a ball, which is lifted out by the workmen and shingled into a bloom, which is subsequently cut up and drawn out into bars.

In this process, the first effect of the heat is the expulsion of water from the ore, which, being thus rendered porous and readily permeable to the ascending current of carbonic oxide (CO), is almost wholly reduced by this gas. The spongy mass so produced is then melted before the twyer, with the separation of the slag from the metal, and a considerable waste of iron is at the same time necessitated, since, owing to the comparatively low temperature employed in this process, it is necessary to maintain a very fluid slag or cinder, consisting essentially of a ferrous silicate of the formula $2FeO, SiO_2$. Such a silicate, in addition to its fluidity, also exercises a decarburizing effect upon the molten iron, whereby its combined carbon is oxidized to carbonic oxide, with the reduction of metallic iron from the slag. In this manner, from the low temperature at which the iron is reduced, together with the maintenance of a very fusible and fluid slag of silicate of iron, the carburization of the metal to the state of pig-iron is prevented, and the product is removed from the hearth in the state of malleable or at most a steely iron.

In India, malleable iron is made direct from the ore in furnaces, with shallow hearths and an artificial blast, resembling the ordinary smith's hearth; or in furnaces with shafts working either with, or without an artificial blast. The charges are however small, the masses or blooms produced varying from 20 to 200 lbs. in weight.

149. Chenot Process.—This process is described, page 209.

150. American Bloomery Process.—Formerly the whole of the iron obtained in England was made by this process, by which malleable iron is made *direct* from the ore at *one* operation. The process is still worked somewhat extensively in the United States and Canada. The following description of the furnace is from the report of Dr. Sterry Hunt:—The *bloomery hearths* or *low furnaces* measure from 27 to 28 inches, by 30 to 32 inches along the sides, and are only 20 to 25 inches in height above the twyer, and from 8 to 14 inches in depth below it. The sides, formed of cast-iron plates, about 1½ inch thick, slope inwards and downwards, and rest, in the more modern of the furnaces, upon the hollow casting of iron which forms the bottom of the furnace, the latter kept cool by water circulating through it; in the older furnaces, instead of hollow iron castings, the hearth is formed simply by beating in clay or slag. The twyer is placed 12 inches above the bottom, and is inclined so as to make the blast strike the middle of the hearth, the twyer opening being a segment of a circle 1½ inches in height, and ¾ inch wide. A water box is let into the twyer plate, through which a stream of water circulates for keeping the twyer cool, the water passing from it to the bottom plate of the furnace, where it serves a similar purpose. In front of the furnace, at 16 inches above the bottom, is a flat iron hearth, 18 inches wide, in the side plate beneath which is formed a *tap hole*, through which the slag is withdrawn from time to time.

The blast is heated to from 500° to 600°F. (280°C. to 320°C.), by passing it through cast-iron syphon pipes placed in chambers above the hearth, and is employed at a pressure of from 1½ to 2 lbs. per square inch, except when smelting the finer magnetic sands, when the pressure is reduced to from ⅞ to 1¼ lbs. per square inch.

The fire being lighted, and the furnace heaped up with charcoal, the powdered ore is scattered at short intervals over the top of the burning fuel. In passing downwards to the twyer the metal is reduced, but without fusion, the grains of metal agglomerating in the hearth to the formation of an irregular mass or *loup*, while the earthy matters are separated as a liquid slag, which is tapped out at intervals. In about three hours fuel and ore have been continuously supplied as the charge worked down, a mass or loup of about 300 lbs in weight has collected, and is lifted by a bar from the hearth, and held for a few minutes before the twyer, so as to obtain a welding heat, when the loup is shingled into a bloom, and is reheated in the bloomery fire for drawing it into bars; the fires thus work continuously, each produces about 2400 lbs of blooms per day of twenty-four hours.

The ores employed in this process are rich and pure magnetic iron ores, and titaniferous iron sands; the latter, owing to their more refractory character, do not give such favourable results as the purer and more easily reduced magnetite, and the process is not applicable to the working of ores containing less than about 50 per cent. of metallic iron.

PRODUCTION OF MALLEABLE FROM CAST IRON, OR INDIRECT PROCESSES FOR THE PRODUCTION OF MALLEABLE IRON.

The *indirect processes*, or methods by which the ore is first smelted in the blast furnace and the pig-iron so obtained, then treated in suitable furnaces for conversion into malleable iron, are of two classes.

The first, where the pig-iron is treated in *open-hearths*, along with coke or charcoal as the fuel, includes the South Wales Process, the process as conducted in the Swedish Finery or Lancashire Hearth, and the Walloon Process of Germany; but all of these, and especially the last-mentioned, are declining in importance.

The second methods are those in which the pig-iron is treated for decarburization, etc., in covered or *reverberatory furnaces*, constituting the puddling processes, and they are by far the most important of the methods for the production of malleable iron.

The indirect processes permit of the use of much inferior classes of fuel and of smelting materials than is permissible with the direct processes; and this is especially the case with the ordinary puddling operations where raw coal and the most inferior class of fuels may be employed, since the fuel does not come into direct contact with the metal under treatment, but is either burnt on a separate grate, or it is in the first instance employed for the generation of gas which is subsequently burnt on the furnace hearth.

The direct methods are only applicable where superior fuels and the richest classes of ores are available, since the ore, flux, and fuel are all in contact on the same hearth; while, owing to the low temperature and extreme fluidity of the slags of ferrous silicate, which are produced in the direct processes, it is necessary to use only such ores as are sufficiently rich to allow of a large percentage of the metal escaping reduction.

CONVERSION OF PIG-IRON INTO MALLEABLE IRON IN OPEN HEARTHS IN CONTACT WITH THE FUEL.

The reactions involved in the conversion of pig-iron into malleable iron in open hearths, do not materially differ from those described for the puddling process, though the furnaces employed and the practical manipulation involved, differ much in detail. The essential differences between the two methods consist in the use of raw coal, and in the *fining* of the metal out of contact with the fuel in the puddling process, whereas in the present processes *coke* or *charcoal* alone are the fuels employed, and the *fining* takes place with the fuel and metal on the same hearth.

151. South Wales Process.—This process, classed sometimes as a variety of the *Walloon process*, is employed in South Wales for the production of a superior quality of iron, required for the manufacture of the so-called *charcoal plates*, which are used in the production of tin plates; and for this purpose pig-iron smelted with cold blast is also often employed.

The furnaces employed consist of a small *refinery* or *running out fire*, connected by inclined channels with two *charcoal fineries*, which are placed in front, and at a slightly lower level than the refinery with which they are connected. The refinery is similar to that described (p. 156), but it has only two twyers, and measures only 18 inches square. The charcoal fineries are rectangular hearths, provided with a single slightly inclined twyer, through which a blast of cold air is delivered, and the hearths are each surmounted by a chimney or stack. The hearth has three sides vertical, while the fourth, or working side, slopes a little outwards, and the bottom plate is kept cool by a current of air passing beneath it.

The charge of 5 or 6 cwt. of pig-iron is introduced into the refinery, is melted down under coke, and refined to a certain extent by blowing in atmospheric air, as described (p. 158).

The imperfectly refined metal is then tapped out from the bottom of the hearth along gutters or channels into the *two* fineries, and are still heated from the working off of the last charge. The slag from the running out fire is excluded from the fineries as much as possible. A layer of slag quickly solidifies on the surface of the metal in the finery, and is removed, after which charcoal is thrown on the top, the blast turned on, and the partially solidified metal broken up. The materials are heaped up on the twyer side, where water is thrown on at intervals to prevent the burning away of the charcoal, of which more is added as required to replace that consumed. The metal is continually raised and broken up by the workmen, and the residual metal collected from the hearth after the withdrawal of the last heat is added to the charge. The slag is tapped out from the finery two or three times during the fining process, which lasts a little over an hour, when the metal is collected into a lump, enclosing much interspersed slag or cinder. The lump so obtained is hammered under the *helve* into a bloom, and either rolled or drawn down under the hammer into a long slab of from 1½ to 2 inches in thickness, which is nicked partially through and broken with a sledge hammer into pieces of about 25 lbs. each, called *stamps*. About three of these stamps are placed on a staff, the end of which is made of the same metal as the stamps, when the pile so formed is reheated in the *hollow fire*, and welded under the hammer. The piece thus produced is nicked on its under surface, turned upon itself, again heated in the hollow fire, and rewelded; in this manner, or by the method of "tops and bottoms," as it is called, both surfaces of the plates are alike. The bloom is afterwards rolled into sheet-iron.

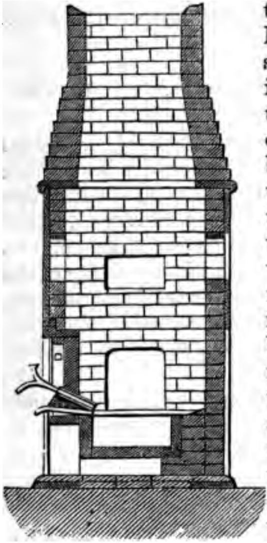

Fig. 35.—Charcoal Finery (Percy).

The finery cinder produced in this process, especially towards its termination, is highly basic containing upwards of 75 per cent. of ferrous oxide (FeO.)

152. The Hollow Fire.—The hollow fire, in which the *stamps* are reheated for welding, is a rectangular chamber without stack; its bottom is formed of cast-iron plates beneath which is an air passage for keeping it cool, and the plates are covered on their upper or working surface with a layer of fire-brick. Coke is the fuel employed, which is placed on the bottom of the chamber through an opening or stoke-hole in the end of the furnace, its combustion being maintained by a blast introduced near the top of the fuel by a twyer inclined slightly downwards. In this manner the upper portion of the chamber is filled with flame, in the midst of which the stamps supported on the staff are inserted, and become heated without coming into contact with the fuel. The flame always escapes more or less around the working door in front of the furnace, but the greater portion of the waste flame is conveyed through an opening in the division wall into a second chamber, where the pile undergoes a preliminary heating before introduction into the hollow fire.

153. Swedish Lancashire Hearth.—The *charcoal finery*, employed in Sweden under this name, consists of a rectangular chamber or hearth, arched over at the top and communicating by a horizontal flue or heating chamber with the stack of the furnace; the hearth is formed of cast-iron plates, and has one twyer delivering a blast heated to about 100°C., or 212°F., by passing it through a tube heated by the waste gases. The hearth being charged with charcoal, the charge of about 2 cwt. of pig-iron is drawn from the flue where it has been placed for a preliminary heating on to the bed of the furnace, when the blast is turned on and more charcoal added. During fusion the highly carburized metal liquates out, and in dropping down before the blast becoming partially decarburized, collects in the bottom, and there slightly hardens, the workmen continually breaking it up and bringing it before the twyer, by which the decarburization or fining is completed; as the process proceeds, the mass becomes less fusible, when the whole is raised to the top, fresh charcoal added, and the heat increased in order to melt the metal thoroughly, for the better separation of the slag and the collection of the metal into a ball. The ball is then taken out and shingled, the bar so produced being cut into pieces, which are reheated in a separate furnace, welded again, and further treated under the hammer or by rolling.

154. Walloon Process of Sweden.—This process is somewhat famous as being that by which the celebrated Dannemora irons (so extensively used in the manufacture of the best classes of steel) are manufactured. The furnace employed is a charcoal finery using cold blast. The hearth is a rectangular cavity bounded by cast iron plates lined with charcoal; it has a tap hole in one side for drawing off only the excess of the slag, since the ball is always worked in a bath of slag, for supplying which finery scraps and hammer slag are melted down on the hearth at the commencement of the process. The pig-iron employed is white or strongly mottled, cast in pigs or slabs some 16 feet long and about 3 inches in thickness, which—the fire being lighted, the hearth full of charcoal, and the blast let on—are placed over the back plate of the hearth, the fore-end of the pig only being inserted into the hearth over the twyer. As the end melts the slab is pushed gradually forward until the whole charge necessary for the production of a bloom of about 100 lbs. has been melted. The charge is continually worked or rabbled from the time the pig begins to melt to the close of the process, which occupies only about thirty minutes, the iron "coming to nature" very readily. Each lump or bloom produced is drawn out under the hammer into a bar, during which process it requires reheating from six to eight times, of which the first heat is effected in the hearth of the finery itself. For this purpose the bloom is held with a pair of tongs in the fore part of the hearth during the melting down of the pig-iron for the succeeding charge; the subsequent heats are, however, effected in a separate fire. The working of this hearth is attended, with a very large consumption of fuel (charcoal), with the maintenance of a higher temperature than is attained in other charcoal fineries, but the loss in the conversion of the pig into malleable iron amounts to about 20 per cent. of the pig-iron employed.

In some districts 2 to 3 cwts. of metal are charged into the furnace in the form of small pigs, instead of the lighter charges described above. The blast for the Walloon furnace is supplied by primitive bellows, driven by cams fixed on a revolving shaft.

In the South Wales process two furnaces are employed, the *refinery* for melting down and partially refining the metal, and the *fineries* where the breaking down and balling up of the charge is completed; but the Walloon process affords an example of a process where the three operations of *melting down*, *breaking up*, and *balling* of the charge are performed as one continuous operation and in one furnace.

CONVERSION OF PIG-IRON INTO MALLEABLE IRON IN REVERBERATORY OR PUDDLING FURNACES.

By far the largest proportion of the malleable iron now manufactured is obtained by subjecting pig or cast-iron to the operation of *puddling*, this process having almost entirely superseded the methods of production in the *finery* or *open-hearth* previously in use. This latter process is not to be confounded with the process of *refining* about to be described; for whereas the operations of the *finery* have for their object the production of malleable or wrought-iron, the product of the *refinery* is only a partially decarburized and imperfectly purified white iron, obtained by the treatment of grey pig-iron on the hearth of the refinery, and which is then cast in a particular manner, adapting it to the requirements of the puddling operation, or it is run directly from the refinery to the puddling furnace. As will be presently indicated, grey iron, owing to its perfect fluidity when melted, and also to the large amount of graphite which it contains, cannot be economically treated alone in the puddling furnace; but by subjecting it to the refining operation it is converted into white iron; thus, it will be observed that the treatment in the *refinery* is only *preliminary* to the puddling process in which malleable iron is produced, while the *finery* process produces malleable iron *direct* from the pig-iron.

155. Refining.—This process is employed in Wales, Yorkshire, and to a limited extent in other iron-making districts, preparatory to the conversion of pig-iron into the *finest* qualities of malleable iron by the puddling process; while, for the manufacture of inferior classes of malleable iron, the pig-iron is not subjected to this treatment, but passes at once to the puddling furnace.

The refining process has for its object the removal of a considerable proportion of the silicon and slag-forming elements from the cast-iron, with a reduction in the amount of phosphorus and sulphur present, as also the partial decarburization of the metal, with the conversion of its residuary carbon wholly into the combined form, this latter being promoted by running the metal from the *refinery* into a long flat chill mould, and quickly quenching with water. By refining, the fluidity of the melted metal is rendered much less perfect, and it is thereby more readily acted upon in the puddling process. Pig-iron smelted by hot blast, usually contains the largest proportion of silicon and other foreign ingredients, and accordingly suffers a greater loss in weight during the refining process than occurs with cold blast pig-iron. The loss in refining amounts on an average to from 10 to 11 per cent. of the pig-iron operated upon.

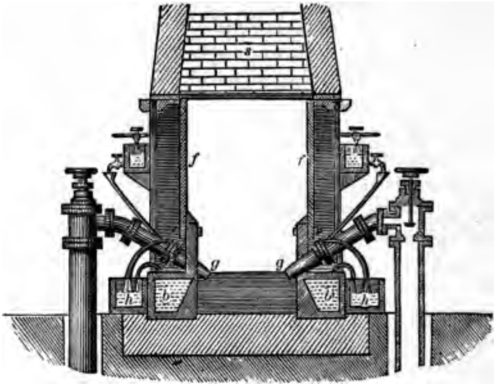

Fig. 36.—Elevation of Refinery.

The furnace employed in refining, and known as the *refinery* or *running-out fire*, consists, as used in Wales, of a rectangular hearth *a*, figs. 36 and 37, about 4 feet square, and from 12 to 18 inches in depth. The hearth is bounded on two sides, and on the back, by hollow cast-iron ***water blocks*** ***b***, ***b***, through which a current of cold water is kept continually flowing; the front is formed by a dam-plate of cast-iron, containing the *tap hole*; *f*, *f*, are cast-iron plates closing the two sides, and secured to the pillars, which carry the stack or chimney *s*, from 16 to 18 feet in height; there are six twyers, *g*, *g*, *g*, three on each side of the hearth, inclined downwards at an angle of from 25° to 30°, the twyers in the two sides being arranged so that each directs the blast towards the space between the twyer openings on the opposite side, so distributing the blast more uniformly over the surface of the hearth; *h*, *h*, are water troughs for receiving the water from the twyers, which serve also to cool the tools employed in working the furnace. The back of the furnace is closed by wrought-iron doors, and the front by a wrought-iron door connected with a lever, by which it can be readily raised or lowered. The tap hole *l*, at the base of the dam-plate, allows the metal and slag to run out into the cast-iron mould *m*, beneath which water is maintained in constant circulation, so as to aid in the quick cooling of the metal, which is further promoted by throwing water on its surface. The cinder or slag remains fluid longer than the metal, and it is tapped from the surface of the refined metal into other moulds placed at the lower end of the mould receiving the metal.

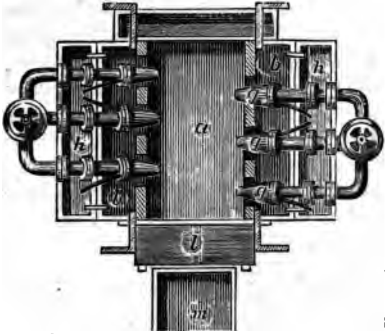

Fig. 37.—PLAN OF REFINERY.

The furnace employed in Yorkshire differs from the last or Welsh refinery, in having but five twyers, placed three on one side and two on the opposite, arranged as before, so as not to be directly opposed to each other.

The furnace being in operation, a quantity of coke is introduced through the folding doors at the back of the furnace, on which is placed alternate layers of pig or cast-iron and coke, until the charge of from one to two tons of pig-iron and scrap has been introduced. A small quantity of hammer scale or slag is also sometimes added, such addition facilitating the process, and diminishing the loss of iron. The addition of a small quantity of lime is also frequently made with a view to the further elimination of sulphur, but this is effected more perfectly by the manganese of the pig-iron, owing to the more fluid slag which it produces. The surface of the charge is then covered with coke, and the fire urged by the blast, when in from one and a half to two hours the whole of the metal has melted and run down into the hearth. Fresh fuel is then added, and the blast under a pressure of from 2 to 3 lbs. is continued for a further period of half an hour, during which time bubbles of carbonic oxide escape from the melted metal, and keep its surface in agitation, whilst silicon and carbon, with smaller quantities of the sulphur and phosphorus of the pig-iron, are oxidized. The silicon is largely and the most rapidly oxidized, with the production of a slag or cinder, consisting essentially of a tribasic silicate of iron (containing from 40 to 60 per cent. of iron), and which floats on the surface of the metal. Fresh coke is added from time to time, and the heat maintained until the action has proceeded sufficiently far, the time varying much according as white or grey iron is under operation, grey pig-iron requiring the longer time for its treatment. The metal and slag are then tapped out together, cooled, and separated in the manner described. About 3 cwt. of coke is consumed per ton of metal, and the weekly produce of the refinery varies from 80 to 150 tons, according as the charge consists of grey or white iron.

The *refined iron*, *fine metal*, *plate metal*, or simply *metal*, as the product obtained by this process is called, is almost silver white in colour, has a bright fracture, the upper portion of the plate being more or less cellular. The plates of metal are from 1 to 3 inches in thickness, a foot wide, and 12 or 14 feet in length, often furrowed on their under surface, and rendered brittle from their sudden cooling, thereby facilitating the breaking of them into pieces suitable for introduction into the puddling furnace.

The following analyses show the very marked decrease in the silicon with the smaller diminution in the amount of the carbon, phosphorus, sulphur, and manganese, effected by the refining process:—

ANALYSES OF REFINED IRON.

	France (*Regnault*).		Ebbw Vale (*Noad*).		Bromford (*Dick*).
	Pig-Iron.	Refined Iron.	Pig-Iron.	Refined Iron.	Refined Iron.
Iron..................	92·3	97·8	...	...	95·14
Carbon..............	3·0	1·7	Graphite 2·40	0·30	3·07
Silicon..............	4·5	0·5	2·54	0·32	0·63
Sulphur	...	...	0·22	0·18	0·16
Phosphorus...... ..	0·2	...	0·13	0·09	0·73
Manganese.........	...	...	0·86	0·24	Trace
Insoluble Matter..	...	...	...	...	0·14

The slag or cinder from the refinery, as already stated, is essentially a ferrous silicate containing from 40 to 60 per cent. of iron with the greater part of the manganese, and a portion of the sulphur and phosphorus from the pig-iron, with the ash of the fuel; it is a dark bluish, or black, vitreous or lustrous mass.

ANALYSES OF REFINERY CINDER OR SLAG.*

	Dowlais (*Riley*).		Bromford (*Forbes*).
	Ordinary Cinder.	Crystallized Cinder.	Crystallized Cinder.
Ferrous oxide (FeO)....	65·52	54·94	61·28
Silica......................	25·77	33·33	22·76
Manganous oxide (MnO)	1·57	2·71	3·58
Alumina...................	3·60	5·75	7·30
Lime........................	0·45	1·19	3·41
Magnesia..................	1·28	0·50	0·76
Sulphur....................	0·23	...	0·46
Ferrous sulphide.........	...	0·27	...
Phosphorus................	1·37	0·99	...
Copper.....................	...	Traces.	...
Percentage of iron	50·96	42·84	47·66

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* Percy, Vol. II.

In Silesia the refining has been effected by treating the iron on the bed of a reverberatory furnace with gaseous fuel, a movement of rotation being imparted to the melted metal on the hearth by the blast impinging obliquely upon it at two opposite sides.

156. Washing Processes.—The washing processes of I. L. Bell and of Baron Krupp are a species of refining operation, in which molten pig-iron is subjected, in a suitable furnace, to the action of refractory ores or cinders, rich in oxide of iron, but not too rich in silica; and whereby the silicon and phosphorus of the pig-iron are very rapidly and almost entirely removed from the charge, whilst the carbon is not appreciably affected. Mr. Bell considers it essential that the temperature employed in this purifying or washing process, although high, should be lower than that at which either puddling or refining is usually carried on, whilst it is absolutely indispensable that rapid contact between the pig-iron and the iron ore or fettling be effected, otherwise the metal solidifies before the dephosphorization is completed. He accordingly employs a water-jacketed, revolving, puddling furnace, in the interior of which a longitudinal shelf is formed, over which, when the lining is completed and the furnace is revolved through half a revolution, a cascade of molten iron and cinder falls, and thus a rapid and intimate mixture is secured.*

At Essen this process is conducted upon charges of from 5 to 7 tons of pig-iron, containing by preference about 1 per cent. of manganese. The pig is melted in a cupola, and run from thence on to the hearth of a Pernot revolving furnace, which is set into slow motion. The hearth of the furnace is first prepared with lumps of a rich but refractory iron-ore, which, if the proportion of silica in the ore is excessive, is mixed with a little lime. A temperature between that of the puddling process and that required to melt steel is then raised, upon which a violent reaction, lasting for from 5 to 10 minutes, ensues. The slag boils over during the process, and the end of the reaction is marked by the sudden evolution of a large volume of carbonic oxide, upon the appearance of which the furnace is stopped, and the refined metal is run out into pigs.

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* *Principles of Manufacture of Iron and Steel* (Bell).

157. Puddling Process.—This process, introduced by Henry Cort in 1784. differs from the methods of producing malleable iron in the *finery* or *open hearth* described (p. 151), inasmuch as *pig-iron* or the *refined metal* from the refinery is puddled on the bed of a reverberatory furnace, or other chamber, which is separated from the grate on which the fuel is burnt; whereas, in the finery, the metal and fuel are brought into contact on the same hearth. The temperature of the puddling furnace is maintained by the heat and flame, produced during the combustion of the gaseous products of the furnace, and the process thus allows of the utilization of raw coals and other inferior fuels, which could not be applied in the finery, where the fuel and iron are brought into contact with each other.

In the puddling furnace introduced by Cort the metal was worked upon a bed formed of sand, but in 1816, or 32 years after Cort, one Rogers substituted an iron bottom protected by a fettling of iron for the sand bottom of Cort, an alteration which materially added to the life of the furnace. The methods of puddling are thus divisible into two classes, the original, known as "dry puddling," and the most recent, known as "wet puddling or pig boiling." In *dry puddling* the decarburization is effected chiefly by a strong current of air (produced by the draught of a chimney or stack), assisted only in a minor degree by the addition of such oxidizing or readily reducible materials as hæmatite, forge-scale, magnetic oxide of iron, and basic slags of ferrous silicate. In *dry puddling*, the refining process, previously described, is a preliminary stage.

If oxidizing slags, cinders, iron-ores, etc., are added to the furnace in such quantities as to afford the chief supply of oxidizing materials, while the air performs this part only in a lesser degree, then the process is designated as *wet puddling* or *pig boiling;* and raw pig-iron or unrefined metal is always the subject of operation, unless the proportion of silicon in the pig-iron is too high, when a little refined iron is sometimes added to the charges, in order to save time in working, and to produce a better quality of iron. The bottom of the furnace in the two cases is slightly altered in depth, form, and the nature of its lining, according as whether dry puddling or pig-boiling is to be conducted upon it.

Grey pig-iron, as requiring a higher temperature for its fusion, coupled with its more perfect fluidity when melted, is not so suitable for conversion into malleable iron as is white iron, which melts at a lower temperature, and which previous to fusion passes through a pasty condition highly favourable to the action of atmospheric air or other oxidizing agent, upon the carbon, silicon, sulphur, phosphorus, manganese, and other elements of the pig-iron, which it is the object of the puddling operation to remove. The treatment of grey instead of white iron in this process entails considerably more labour upon the puddler, for unless such metal is continually stirred, or as it is called *rabbled*, so as to bring fresh portions in contact with the air and slag, the iron will sink down as a fluid mass beneath a layer of molten slag or cinder, which prevents the contact of air and thus delays the *fining* of the metal, with the necessarily increased expenditure attendant thereon; hence one of the necessities for converting grey into white iron in the refinery, before subjecting it to the puddling process.

The first stage in the operation of puddling consists in the removal, to a great extent, of the silicon; and the conversion of any grey into white iron, that is, any graphite that may be present must pass into the state of combined carbon before any appreciable decarburization of the metal occurs. When this stage is completed, the manganese, phosphorus, sulphur, and carbon, with a proportion of iron, are oxidized, either by the free oxygen of the atmosphere, or by the oxygen of the oxides of iron added to the charge. A fusible slag or cinder of silicate of iron and manganese with earthy matters, phosphoric acid, etc., is thus produced, while at the same time carbonic oxide is evolved, and burns with its characteristic flame in jets from the surface of the molten metal.

In the *boiling or wet process*, the decarburization is chiefly effected by the reduction of the oxides of iron contained in the cinders and slags added to the charge; and this reduction of iron from the slag, with decarburization of the melted metal, takes place the more readily when the slag is most basic, that is, richest in oxide of iron. Thus in the earlier stages, or during the melting down of the iron, the silicon is being oxidized, and the slag is highly siliceous, hence but little reaction ensues between it and the carbon of the pig-iron; but as the process proceeds, and iron begins to be oxidized by the air, then the basicity of the slag increases, and a reaction ensues between the ferrous oxide of the slag and the carbon of the pig-iron, by which carbonic oxide is copiously evolved, and escapes through the liquid slag, while a corresponding decarburization of the pig-iron, and reduction of iron from the slag or cinder takes place.

The elimination of sulphur from the pig-iron during the puddling operation is always very imperfect, a portion only passing into the cinder, probably as ferrous sulphide.

Phosphorus, when present in the pig-iron to be puddled, always prolongs the puddling operation, but during the process it is oxidized to the state of phosphoric anhydride, and in this form it always occurs in the tap cinder.

About 80 per cent. of the phosphorus present in the pig-iron is removed during the puddling process, but the exact reactions by which the elimination is effected are as yet imperfectly understood. Percy suggests that it is probably separated by a kind of liquation, according to which theory the phosphorus first enters the tap cinder as a phosphide of iron, which liquates from the malleable iron when the latter is in its pasty condition, and that the phosphorus is thus subsequently oxidized to phosphoric anhydride. More recent observations and experiments demonstrate, however, that phosphorus is eliminated from pig-iron during the decarburization of the latter, whenever such decarburization is effected under strongly oxidizing influences, and in contact with a *fluid, highly basic oxide or slag.* These conditions prevail during the later stages of the basic Bessemer process (p. 268), and also during the greater part of that stage of the pig-boiling process in which the iron remains perfectly fluid upon the bed of the furnace, and before any separation of granules and solidification of the metal takes place.

As already stated, in pig-boiling the silicon is the first element to suffer oxidation, silica, SiO_2, being produced, and this enters the slag rendering the same highly silicious, but the silicon is practically all oxidised before the close of the first few minutes of the fluid period. After the silicon has been thus almost wholly oxidized, then the cinder or slag becomes rapidly more basic, and the phosphorus suffers oxidation to phosphoric anhydride, P_2O_5, which then combines with ferrous oxide, and the phosphorus thus escapes into the slag as ferrous phosphate. Whatever phosphorus is separated during the puddling process, is thus practically effected before the boil or decarburization stage commences.

158. Puddling Furnace.—The puddling furnace is a reverberatory furnace in which the proportion of grate area to that of the bed is very large, but the size of grate varies according to the kind of coal consumed—from one-half to one-third the area of the bed of the furnace. Figs. 38, 39, and 40* represent a South Staffordshire furnace which may be taken as a type of this class, though the exact form of bed, and method of supporting the cast-iron plates forming the bottom, differ in various districts. The bed *a* of the form shown in fig. 40, is separated from the rectangular fireplace *b* by a low hollow fire-bridge *c*, and from the flue *d* by a similar bridge *e* called the flue-bridge. These bridges are here shown hollow, to allow of the circulation of air through them; in other furnaces, instead of the separate iron plates here illustrated, hollow castings are substituted, which form a channel around the bed, in which a current of water circulates. The roof, formed of fire-brick, is a low flat arch, slóping slightly towards the flue end, the flue itself being built with a slope downwards to the base of the stack; the brickwork of the furnace is supported by cast-iron side plates bolted together, and tied to those of the opposite side by tie-rods passing over the top of the furnace. The bars of the grate are ordinary bars of wrought-iron, supported on bearers at their extremities; there is no furnace door, the fuel being charged through an opening *f* in the front or working side of the furnace, situate about 10 inches above the fire-bars, over which the fuel is spread by the workman using a hooked bar of iron; and when the firing is completed, the aperture is closed by inserting lumps of coal in the opening, on to which a small quantity of small coal is thrown. The flue and fire-bridges are formed of fire-brick, encasing the frame of the cast-iron

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* Percy, Vol. II.

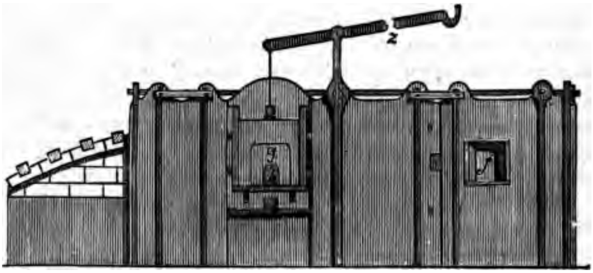

Fig. 38.—Elevation of Puddling Furnace.

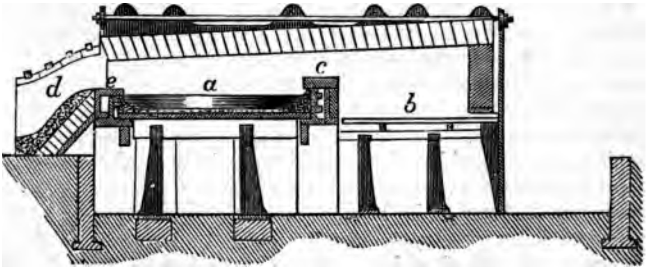

Fig. 39.—Vertical Section of Puddling Furnace.

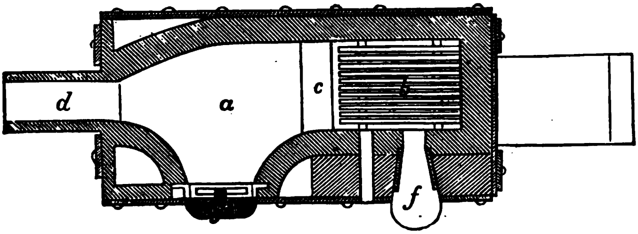

Fig. 40.—Plan of Bed of Puddling Furnace.

bottom, beyond which the upper course of brickwork, formed by quarries or slabs of fire-brick, is made to project inwards as shown, to allow of the introduction of the *fettling* or lining of refractory material for protecting the side plates. The bottom of the furnace is formed of cast-iron plates rabatted together, and supported upon pillars or bearers resting on side plates or brackets also of cast-iron. The working door *g*, placed at one side of the furnace, consists of an opening about 10 inches above the furnace bottom, and closed by a door formed of fire-brick slabs or quarries fixed in an iron frame, and suspended by a chain from the lever *z*, by which it can be raised for introducing the charge or withdrawing the puddled ball; a notch *h*, formed in the lower edge, and called the *stopper hole*, is for the introduction of the iron bar or *paddle* used by the puddler in *rabbling* or stirring the metal, the side of the notch acting as a fulcrum for the bar; below the working door is the *tap hole i*, stopped with sand during the working of the furnace, and through which the slag, or, as it is called, *tap cinder*, which remains on the hearth, is withdrawn at intervals as required. The stack of the furnace, the height of which varies considerably according as it is connected with one or more furnaces, if for one furnace only, is usually from 30 to 50 feet in height, and is surmounted by a flat plate or damper connected to one end of a simple lever, from the opposite end of which is suspended a chain, sufficiently long to be within reach of the puddler, the proper regulation of the draught forming an important part in the puddling operation. The working bottom of the furnace used in *pig boiling* or *wet puddling*, is formed by covering the iron plates already mentioned with a coating of refractory material rich in oxide of iron, such as tap cinder, hammer scale, etc., mixed with broken up bottoms of old furnaces; for this purpose a layer of broken slags, hearth bottoms, etc., are first introduced, and the heat raised so as to fuse or soften it, when it is spread evenly over the bottom, forming a layer of about 3 inches in depth; the side plates are covered, or as it is called *fettled*, with a lining of broken up, roasted *tap cinder*, called *bull dog*, which is rammed in under the projection of the fire-brick quarries on the top of the fire-bridge, and then the surface is levelled up with a paste of soft red hæmatite called *puddlers' mine*, the fettling so prepared extending more or less over the furnace bottom.

If a new furnace bottom has been put in, the first heat should consist of scrap iron, with a small quantity of refined metal; when, by the high temperature and oxidizing atmosphere maintained in the furnace, the bottom becomes thoroughly consolidated and coated with a layer of slag consisting largely of oxide of iron, which is but little acted upon by the silicon of the pig-iron introduced in future operations. Fettling of the side plates is required after each heat, and after each shift of twelve hours sufficient scrap iron to form a ball is introduced into the furnace, and worked into a bloom, for the purpose of coating the bottom of the furnace with oxide of iron. A puddling furnace in continual use will require rebuilding in about six months.

Of the numerous proposed improvements in the class of puddling furnace already described, may be noted that of Detmore, tried at Ebbw Vale, and consisting of an arrangement for introducing a blast under the grate, using a *closed* ash-pit, with washed small coal as fuel; another introduces the blast below the grate, with an *open* ash-pit, when small coal, half caking, and half free-burning was proposed to be used.

Double puddling furnaces have of late been received with favour, as admitting of heavier charges with a larger production and economy in fuel; but the wrought-iron produced is not likely to be so uniform in quality, due to the increased amount of air and the longer time employed by puddling in the double furnaces, as also from unequal skill in the puddlers working the two sides of the furnace. In these furnaces the hearth and grate are both made larger than single furnaces, and the two working doors are placed one along each side of the furnace, through which the metal is worked by two men at the same time, viz., one at each door.

159. Manipulation of the Puddling Process.—The details of the working of the puddling furnace differ according as white, grey, or refined iron, or a mixture of these with hammer slag, etc., is under treatment. If the charge consist of white or forge pig-iron alone, the heat is maintained higher at the commencement of the operation than when grey iron constitutes the charge. The proper regulation of the damper, as controlling the temperature of the furnace and amount of air passing through it, is of considerable importance, and requires to be raised and lowered several times during the progress of a single heat.

In conducting the puddling process, the furnace heated from a previous operation, and containing some rich cinder from the previous charge, is charged with about 4½ cwt. of metal, introduced through the working door, the latter being then lowered, fixed, and luted in position; the damper is raised, and the fire made up, when, in about fifteen minutes, the puddler inserts his *paddle* or bar through the stopper hole and moves the pigs about, so as to heat them and the furnace bottom more uniformly, and in from thirty to thirty-five minutes the first or melting down period is completed; the damper is now lowered, and the metal continually stirred, or, as it is called, *rabbled*, so as to thoroughly incorporate the metal, cinder and hammer scale or mill cinder with the charge, after which the damper is raised, and in about forty-five minutes from the commencement, the bath of metal swells and rises up rapidly; jets of carbonic oxide, due chiefly to the oxidation of the carbon in the pig-iron, by the reaction between it and the oxidized compounds of iron existing in the basic slag called *cinder*, which is mixed with and covers the metal, burning with its characteristic blue flame from all parts of the surface of the bath, gives to it the appearance of ebullition or *boiling;* during this stage, which lasts about a quarter of an hour, the puddler, moving his paddle or bar continually from the centre of the bath towards the bridges, rabbles vigorously the metal in all parts of the bath. The metal then begins to thicken, the cinder gradually sinks, and the surface exhibits bright points or specs of malleable iron, or, technically, the iron *comes to nature*, the points, increasing in size, become pasty masses, which are broken up by the workmen, and the heat somewhat raised so as to effect the better separation of the cinder or slag from the metal, when the detached particles of metal are rolled over the surface of the bed, until the nucleus so commenced with, collects upon itself sufficient metal to form a ball of from 70 to 80 lbs. in weight, which is then rolled towards the fire-bridge, where it remains until the whole charge has thus been collected or *balled up* into about six balls; a final heat is given so as to promote the ready expulsion of the cinder, and the welding together of the particles of iron under the hammer, squeezer, or other shingling machine to which the puddled ball is at once transferred. The balls are drawn separately to the working door of the furnace, and lifted by a pair of tongs with curved jaws from the furnace to an iron truck, or they are dragged along the floor to the shingling apparatus, the working door being closed and the damper down, so that the furnace is kept filled with a smoky flame, preventing the oxidation of the other balls during the treatment of the first.

The cinder, which only requires to be tapped out after each second heat, is tapped into a wrought-iron waggon placed under the tap-hole, immediately after the withdrawal of the last ball; but in dry puddling, where white or refined iron only is treated, the amount of silicon not being so great as in the last or boiling process, where mixtures of grey, mottled, and white iron are introduced, less slag is produced, and hence requires tapping out only after several heats have been worked off.

The whole operation, from introducing the charge to the withdrawal of the last ball, constitutes a *heat*, and lasts about an hour and a half, but may be longer or shorter according to the amount of impurity present in the pig-iron, the presence of sulphur and phosphorus in the pig-iron especially retarding the conversion into malleable iron. In Staffordshire, in a *turn* or *shift* of twelve hours, from five to seven heats are worked off; but in Scotland the pig, being a dark grey silicious metal, smelted from blackband ores, only from four to five heats are worked off in the same time; and at Low Moor, Bowling, Farnley, and other districts of Yorkshire making best qualities of malleable iron, the pig employed is cold blast iron, usually refined before puddling, and puddled in charges of from 2 to 3 cwt., in slightly smaller furnaces, maintaining a somewhat higher temperature than the former, and the rabbling is more continuous than is practised in Staffordshire. With this nine or ten heats can be worked off in the day of twelve hours.

Small quantities of Cumberland hæmatite, or of peroxide of iron, are added at some works to assist in the conversion by the boiling process. The addition of a mixture known as *Schafhäutl's* powder, consisting of common salt, peroxide of manganese, and clay, is also sometimes made with a view to the more perfect elimination of the sulphur and phosphorus in the pig boiling. Scrap iron added towards the end of the operation is considered to improve the quality of the product.

In *puddling by the dry method* (that is, in a furnace of which the iron bottom is coated with but from 1 inch to 1½ inches of a lining, consisting largely of oxide of iron, formed by working a ball of scrap iron on the bed while maintaining an oxidizing atmosphere in the furnace, and then spreading the oxide while at a high temperature over the furnace bottom; or, as formerly, in a furnace the bottom of which was simply covered with sand, thinly glazed with slag), the charge is placed around the sides of the bottom of the furnace, the centre being kept empty. When the metal assumes a pasty state, the damper is lowered to prevent its becoming perfectly fluid; and while in this pasty condition, it is drawn down towards the middle of the hearth, broken up, and rabbled, so as to thoroughly mix the metal with the oxide of iron formed during the first or melting stage, and with that added at intervals in the form of hammer scale. The rabbling is continued, and reaction ensues between the carbon, hammer scale, and oxygen of the air, but the decomposition is not so vigorous as in the boiling process; as before, when the metal "comes to nature" or to "*dry*," it becomes less fusible, and the damper is raised to allow of the metal being balled up. This process is attended with the formation of a smaller amount of slag or cinder, due to the smaller amount of silicon in the metal treated, is of shorter duration than the wet or boiling process, and accordingly consumes less fuel; but it can only be applied economically to white or refined iron, and unless comparatively pure ores have been employed, the malleable iron produced is inferior in quality. In dry puddling the heat does not rise so high as in "pig boiling," and in working 4½ cwt. charges of refined metal in a furnace fettled with tap-cinder, the only slag, cinder, or oxidizing materials introduced is about 2 cwts. of scale from the shingling hammers. From charging the furnace to the withdrawal of the last ball occupies from 75 to 80 minutes, of which the melting stage lasts, as in pig-boiling, about 35 minutes, whilst the melted (fermenting) stage and the boil together occupy about 30 minutes, after which the balling of the charge commences.

160. Low Moor and Bowling Iron.—The ore employed at Bowling and Low Moor for the production of the best iron of the works of this district, is a dark brown argillaceous ironstone occurring in the coal measures of the locality, which yields in its raw state, about 32 per cent., or after calcination, 42 per cent. of iron. This ore is smelted with coke from what is known as the "*better bed coal*" of the district. About 4 tons of the raw ore, or 2 tons 7 cwt. of the calcined ore, with 18½ cwts. of limestone obtained from the neighbourhood of Skipton, and 2¼ tons of coke from the above coal, are required for the production of 1 ton of pig-iron. For conversion into plates, etc., the pig-iron is conveyed at once to the refineries, and the yield of about 2 tons of *refined metal* obtained from each finery is run into a mould which is cooled by water, and which measures some 12 feet in length and 4 feet in width. The *plate metal* so obtained is then puddled in charges of about 3 cwt., each furnace working off ten such charges per day, and the puddled ball or bloom is shingled under the hammer for the expulsion of slag, scoria, etc., and formed into slabs, known as "stampings" or "noblins." The *stampings* are broken up, piled, reheated, and hammered into blooms or billets, which are then transferred to the mill, and, after again reheating, are rolled into bars, angle-irons, or other forms; while the *noblins* are subjected to a similar treatment to the stampings, except that they are formed into blooms suitable for rolling in the plate-mill for the production of plates, etc.

161. Loss in Puddling.—The loss of iron in the conversion into malleable iron by puddling varies much according to the purity of the pig-iron; the less silicious the pig, and the larger will be the yield. In "pig boiling" the loss is greater than in dry puddling, but it is not so great as the total loss entailed by refining and then of puddling the refined metal. In Staffordshire the loss of weight between the pig-iron charged and the puddled balls produced is from 7 to 10 per cent.; while pig boiling in Scotch ironworks, where a silicious pig smelted from black-band iron ores is treated, the loss is from 15 to 18 per cent. of the weight.

162. Tap Cinder.—The slag, or, as it is called, "*tap cinder*," produced in the puddling operation, is a highly basic silicate, containing from 45 to 55 per cent. of metallic iron, existing as ferrous and ferric oxides, but the cinder contains in addition usually manganous oxide, alumina, lime, magnesia, ferrous sulphide, and phosphoric anhydride. The composition of tap cinder varies at different stages of the puddling process. In the earlier or melting-down stage it is more silicious, owing to the oxidation of the silicon of the pig-iron by the oxygen of the atmosphere, and also from the presence of the sand which is charged into the puddling furnace attached to the surfaces of the pigs of iron; while at the end of the operation, when the metal comes to nature, the heat is partially maintained by the oxidation of the iron itself, and an increased basicity of the cinder results.

ANALYSES OF TAP CINDER.

	Cinder from Boiling of White Iron. (*Riley*).	Staffordshire Cinder. (*Percy*).
Silica	7·71	23·86
Ferrous oxide (FeO)	66·32	39·83
Ferric oxide (Fe_2O_3)	8·27	23·75
Manganous oxide (MnO)	1·29	6·17
Alumina	1·63	0·91
Lime	3·91	0·28
Magnesia	0·34	0·24
Ferrous sulphide	...	0 62
Sulphur	1·78	...
Phosphoric anhydride	8·07	6·42
Copper	Traces.	...
Metallic iron	57·37 per cent.	47·60 per cent.

163. Gas Furnaces.—The construction of puddling furnaces, adapted to the use of gaseous fuel, varies with the materials employed for the generation or production of the gas, and the mode of effeecting its combustion.

The Carinthian gas furnace, for consuming the gases produced from air-dried wood, lignite or peat, consists of a rectangular chamber or *producer*, of considerable depth, which is built at one end and separated by a bridge from the hearth of the furnace; a second bed, which is heated by the waste gases, is placed between the furnace hearth and the stack, and on this the metal for the succeeding charge is first heated. The combustion in the producer is maintained by a stream of air, at a pressure equal to about half an inch of mercury, which is introduced by a pipe into the bottom of the chamber; while the combustion of the gases is effected on the hearth or bed of the furnace by a blast of air, first heated to about 200° C. or 392° F., by circulating it through the hollow cast-iron bottom plates of the bed. The blast is introduced into the furnace by an oblong inclined twyer immediately above the firebridge, and which extends for the full width of the furnace.

164. Siemens' Regenerative Gas Furnace.—In these furnaces inferior qualities of fuel, as coal slack, coke, lignite, and peat can be utilised, thereby effecting a considerable saving in the cost of fuel; a higher and more uniform temperature can be maintained than is attainable in the ordinary furnaces, with a greater purity of flame; and an oxidizing, neutral, or reducing flame can be obtained by varying the relative proportions of air and gas admitted to the furnace.

The furnace consists of three parts, 1° the *producer* or chamber in which the gases are generated; 2° the *regenerators* or chambers for absorbing and storing up the heat of the flame and waste gases as they leave the furnaces, and which heat is subsequently used in heating the air and gases as they pass for combustion on to the furnace bed; and 3° the furnace proper.

The *Siemens' gas-producers* or *generators* are described (p. 62); but the Siemens' regenerative gas furnace may be worked in conjunction with either this, the Wilson, the blast-furnace, or any other type of producer which maintains a constant pressure of combustible gases from the producers towards the regenerators and the furnace.

The *regenerators* are vaulted chambers of fire-brick built beneath the furnace. These chambers are each filled with an open chequer-work of fire bricks, as shown in fig. 55, p. 236, thus allowing of the passage of air or gases between the bricks. The regenerators are worked in pairs, which admit air and gas respectively to the furnace, and of these the air regenerator is considerably larger than that admitting the gas, the maximum proportion being about 7 to 4. The gases having undergone combustion on the furnace hearth, the gaseous products are drawn down by the draught of the chimney, through the pair of regenerators at the opposite end, whereby, instead of the flame and products of combustion escaping to the chimney at a very high temperature, the heat is absorbed by the bricks in the regenerators, and the gases pass out at the chimney, having a temperature of only about 149° C. or 300° F. The course of the escaping gases is from above downwards through the regenerators, whence the upper layers of brickwork are somewhat more heated than the lower courses.

The *furnace* as applied to puddling, is similar to that illustrated in fig. 55, p. 236, as used for steel melting, but differs from it in being fettled with the usual basic lining of iron oxides, bull-dog, etc., employed with the ordinary puddling furnace. The bed is as usual formed of cast-iron plates, while the sides are hollow boxes, kept cool by the circulation of water through them; the water after circulating around the sides passes into a tank beneath the bottom, when the steam evaporated therefrom assists in keeping the bottom plates cool. At each end of the hearth of the furnace are five openings or ports, three of which are connected with the air regenerator, and deliver hot air to the furnace hearth, whilst the other two ports *b b*, fig. 55, p. 236, are connected with the gas regenerator and deliver the gas to the furnace. The ports are arranged alternately, the two outside and one central port being air ports, whilst the second and fourth are for the admission of gas. The air ports are also made to deliver the air above the point at which the gas is admitted, and in this manner the gas and air are mixed as thoroughly as possible before combustion ensues. The gas and air are thus admitted at the same end of the furnace, and are withdrawn through the corresponding openings or ports at the opposite end, passing in their course through the pair of regenerators at that end on their way to the stack.

In front of the regenerator chambers is a cave or vault, in which are placed suitable reversing valves, by which the direction of the currents of gas and air can be made alternately to enter the furnace at the one or other end, and be withdrawn from the opposite end of the furnace. This alternation of the direction of the currents is under the control of the workman from the charging platform of the furnace.

In working the furnace, the gas and air are controlled by independent valves, and each enter at the bottom of separate regenerators, thus passing from the colder to the hotter portion of these chambers. The gases and air thus heated then mix with each other at the bridge of the furnace, where combustion or chemical combination ensues between the two, attended with the production of a most intense heat; and by admitting a greater or less proportion of air into the furnace, an oxidizing, neutral, or reducing flame can be maintained; as also by allowing a larger or smaller volume of gases to enter, the temperature of the furnace can be regulated. On first lighting the furnace, the air and gases meet in the furnace chamber or hearth in a cold state, and require to be ignited, after which combustion will continue, and the temperature will be gradually raised, while the regenerators at the opposite end of the furnace to that at which the gases are admitted become heated; after effecting this, the current is reversed, and the gases and air pass through the heated pair of regenerators, abstracting heat therefrom, while the opposite pair of regenerators are being heated by the escaping flame and products of combustion.

By the use of this furnace in the puddling process, a saving of from 7 to 10 per cent. is effected in the amount of iron wasted, and the saving in fuel is very large, variously estimated at from 20 to 50 per cent.; the furnace also works off a greater number of heats per shift; but in working upon pig-irons containing sulphur and phosphorus, these elements do not appear to be so perfectly removed as in the ordinary furnace, and the product accordingly is often inferior in quality.

165. Bicheroux Puddling Furnace.—This is a gas puddling furnace working without regenerators. Each furnace is built as in the Boëtius furnace, with its own gas-producer, in lieu of the ordinary fire-bars. The producer is about the same width as the furnace, and in construction is similar to the Siemens' producer already described. The gases from the producer pass from the top of the same, by a short horizontal flue, to a vertical slot corresponding in position to the fire-bridge of the ordinary furnace; here, also, the air required for combustion is admitted through a number of small openings. In this manner almost perfect combustion of the gases ensues, the necessary draught being supplied by a chimney built as usual. Although without a regenerative apparatus, yet the air for combustion is drawn from the chimney end of the furnace, and is circulated through a flue, built beneath the hearth for its full width and length, and whereby the temperature of the air is considerably increased before it issues to the furnace for the combustion of the gases.

In some modifications of this furnace, for puddling purposes the air and gases first meet in a separate combustion chamber, placed between the producer and the furnace hearth, in which, however, only partial combustion of the gases is effected; the flame and gases passing from thence on to the puddling hearth where the combustion is completed. The construction of the producer has also been the subject of modification, according to the character of the coal used in different localities; also for increasing the heating surface over which the air passes before meeting the gases on the furnace hearth. The latter object is effected by circulating the air in flues around the sides of the producer itself.

166. Casson-Bicheroux Puddling Furnace.—This furnace, as applied to puddling purposes, is much the same as that described (p. 200) for reheating purposes, except that the producer is erected immediately behind the furnace without any intermediate gas-flue,* and the air in the Casson-Bicheroux puddling furnace is heated by circulating it beneath the neck and bottom of the furnace. A chimney draught is insufficient for these puddling furnaces, and it becomes necessary to work both gas and air under the pressure of a forced blast.

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* *Proceedings Iron and Steel Inst.* 1884.

167. Boëtius Furnace.—This is an arrangement of furnace in which, instead of the ordinary stoke-hole and grate-bars, a gas-producer is applied and works direct to the furnace.

168. Price's Puddling Furnace.—This is a double furnace fitted with the usual doors, plates, etc., like an ordinary puddling furnace, and it works at Woolwich with a cinder bottom. Price's furnace is a modified gas furnace working with a blast of air from a Lloyd's blower, which blast first enters into an air vessel or receiver, and then passes into a closed ashpit beneath the fire-bars. The furnace is without regenerators. At the end of the furnace hearth, remote from the fire-bars, is a *dandy* or chamber through which the flame and heated gases from the furnace pass, in order to warm up the metal of the charge preparatory to its introduction on to the furnace hearth. From the dandy the heated gases return over the roof of the furnace, and at the grate end of the hearth are split into two currents, which then circulate around an elevated vertical retort or chamber before passing to the stack. The vertical retort just mentioned is thus maintained at a red heat, and it is kept filled with coal charged from a hopper fitted at its top. The lower end of the retort is closed by a slide, which can be opened as required, so as to drop the carbonized fuel on to the dead-plate of the grate, and it is from thence pushed forward by the workman, through the stoke-hole, on to the fire-bars. Vigorous combustion of the fuel upon the grate is kept up by a blast of hot-air introduced, as already mentioned, below the grate bars; and the gaseous products of the destructive distillation of the coal in the retorts, passes out by the bottom of the same, and are drawn by the chimney draught over the mass of burning fuel on the bars, where they at once take fire. In this manner by the combustion of the hydrocarbons distilled from the coal, and of the carbonic oxide rising from the great body of burning coke on the fire-bars, a large volume of flame is produced, whereby a very elevated temperature becomes attainable, and a considerable economy in fuel is said to be effected at Woolwich, by the use of this furnace.

169. Mechanical Puddling.—The work of the puddler is more laborious than any other involved in the manufacture of iron, and for lessening its amount and rendering it more simple, various contrivances have been proposed. Of the mechanism applied to, or external to the furnace itself, for imitating the movements and action performed by the puddler with the rabble, are the various mechanical rabbles, etc. Thus, Nasmyth proposed to introduce high pressure steam through a tubular rabble into the contents of the furnace; but its use has been discontinued. The mechanical rabble proposed by Mr. Eastwood, is a tool suspended from an overhead lever, and it is actuated by a screw and worm gearing, whereby a compound motion is produced which has the effect of moving the rabble over every portion of the surface of the hearth. Amongst the other more or less promising arrangements of mechanical rabbles, should be mentioned that of Mr. Pickles, which, by a suitable arrangement of cranks, levers, and connections, there is given to the rabble a reciprocating motion across the hearth of the furnace, together with a circular motion through a definite arc of a circle, and the combined result of these movements is a sweeping motion over all parts of the hearth of the furnace. Other arrangements differing in their mechanical details, but providing for the same motion, and applied with some success, are those of Whitham and of Griffiths, whilst Morgan proposed a four-pronged rabble, which, passing through the roof of the furnace, is simply revolved by suitable means, and thus stirs about the fluid metal upon the hearth. None of these contrivances have, however, come into general use, since they do not assist the puddler in balling-up the charge, and although they enable somewhat heavier charges to be worked up to the balling stage, yet this very arduous operation still remains to be effected by manual labour alone.

The same remark applies to methods such as those of Ellerhausen, who proposes, as described under his steel process, to effect a mixture of the liquid pig-iron, as it runs from the blast furnace, with oxidizing materials such as hæmatite or magnetite, instead of making the mixture on the hearth of the puddling furnace as practised in ordinary puddling. Other and more promising methods for reducing or superseding the manual labour of the puddler, are to be found in the introduction of furnaces with hearths revolving either in a vertical, or in a horizontal plane. Of the first mentioned, the proposals of Maudsley, Tooth, Menelaus, Bessemer, Danks, Siemens, Spencer, etc., ought to be mentioned; whilst of furnaces whose hearths revolve in a horizontal, or approximately horizontal plane, the most noticeable is that of Pernot.

The great difficulty with furnaces revolving in the vertical plane, has been to obtain a refractory oxidizing lining, capable of withstanding the mechanical abrasion of the large rolling ball of metal, and the corrosive action of the slag. Although both Danks and Siemens appear to have overcome this difficulty, still these rotating furnaces have now practically disappeared from the works of this country, and are working only to a limited extent in America. The use of the Pernot and other horizontally revolving hearths, have also only met with a very limited degree of favour.

170. **Siemens' Rotary Furnace.**—This furnace is described under Steel (p. 210).

171. **Danks' Furnace.** — The working part, bed or refinery, of this furnace, consists of a revolving vertical chamber A, built up of cast-iron plates, and lined with a very refractory material; it is supported and kept in position by four rollers *b*, *b*, and it is rotated by the spur wheel *c* gearing with a suitable pinion. The pinions are driven by a small reversible engine attached to each furnace. The ends of the chamber are contracted in diameter, one extremity communicating with the chamber or fireplace B, while the other end opens into the movable chamber or elbow flue C, leading to the fixed chimney D. Into the ash-pit E, closed by folding doors during the working of the furnace, is introduced a fan blast, and at the grate end of the furnace is a blast-main *m*, communicating by a number of small twyers, *n*, *n*, *n*, with the interior of the furnace, introducing a blast above the fuel. The combustion of the fuel is thus rendered more perfect, the supply of air being regulated by a valve under the control of the workman, who can thus adjust the temperature of the furnace according to the requirements of each stage of the process. The fire-hole, unlike the ordinary puddling furnace, is closed by a door, kept cool by a coil of pipes surrounding it, through which cold water circulates; in a similar manner the bridge between the fire and the rotating chamber, and also the end plates of

the revolving chamber most exposed to the heat, are kept cool. The movable chamber or elbow C, through which the gases pass from the chamber A to the chimney D, is suspended

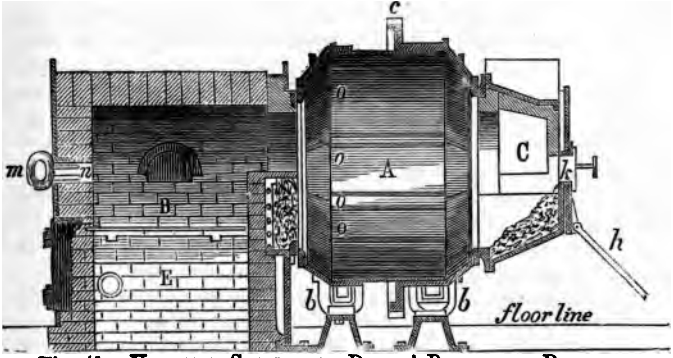

Fig. 41.—Vertical Section of Danks' Revolving Puddling Furnace.

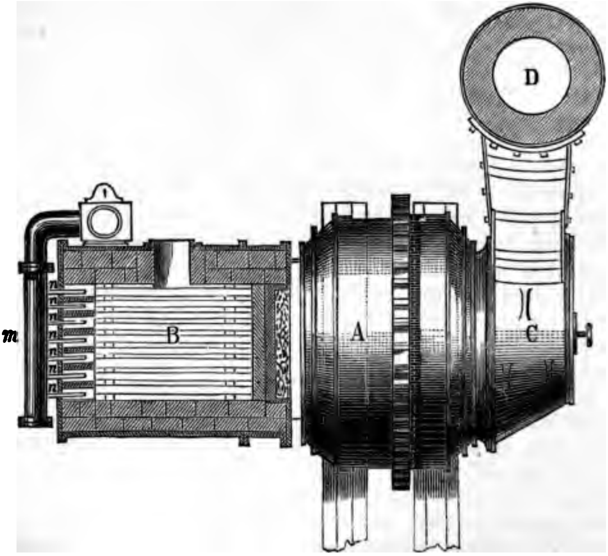

Fig. 42.—Plan, Half in Section, of the Danks' Puddling Furnace.

by rods from a carriage sliding on an overhead jib or rail, and is kept in its place, except when charging or removing a ball, by the supports *h*; in the end of C is a *stopper hole k*, through which the progress of the operation within the puddling chamber can be observed. The revolving chamber, formed of cast or wrought iron segments connecting its two ends, is fitted with hollow ribs *o*, *o*, *o*, *o*, running lengthwise, which serve to keep the plates cool, and also to hold the *fix* or *fettling*.

The inside of the revolving chamber is first lined with an *initial* lining of a pulverized iron ore and lime, made into a thick paste with water, upon which, when dried, is thrown a quantity of pulverized iron ore or hammer slag, the chamber is then heated and revolved slowly, until the initial lining is completely glazed; upon the initial lining so prepared is introduced an inner lining, and for this purpose iron ore, as pottery mine and scrap, are then introduced and melted, forming the *fixing*, and into the melted bath or fixing so formed, lumps of iron ore, as ilmenite (a titaniferous iron ore), are thrown, the lumps of ilmenite projecting above the surface of the bath; this is allowed to set, when another layer of fixing and ilmenite is introduced in the same manner, the operation being repeated until the chamber is completely fettled. The ores used in fettling this furnace are the ordinary fettling materials used for puddling furnaces, such as Bilbao ore, "blue billy" (the residue from the burning of iron pyrites at sulphuric acid works), and hæmatites; but the slags, bull-dog, etc., ordinarily used are unavailable.

The charge of pig-iron is inserted at the chimney end, and as it melts, the revolving chamber A is set in motion; the iron is then carried partially around and rolls down the sides to the bottom of the vessel, and as it melts is carried farther around, running and dropping continually from the sides and top towards the lower part of the chamber, thus exposing the metal thoroughly to the action of the heated air and gases. In these furnaces the charge, from 600 to 700 lbs., is larger than the charge of the ordinary furnaces, and is collected by the furnace into one ball, which is withdrawn through the end, by removing the elbow flue C, and inserting a large forked lever carried by a crane, when, by a small rotation of the chamber, the ball is turned on to the forked end of the lever, which is then withdrawn, and the ball conveyed to be shingled.

The puddled balls obtained range about 10 per cent. heavier than the charge of pig-iron introduced, probably due to the reduction of an amount of iron from the ore used as fettling.

172. Crampton's Furnace.—This furnace consists of a revolving chamber with a movable flue-piece at one end, and to the outer or end plate of the latter, is attached a trunk or tube-piece, which is bell-mouthed towards the furnace. Through this trunk a regulated supply of *coal-dust* and of atmospheric air are automatically injected into the furnace, in the proportions necessary to ensure the complete combustion of the coal. The tube is provided with several feathers running in the direction of its length, and these aid in the better distribution of the coal within the chamber, by preventing the coal from settling upon the lower side of the tube-piece in its passage through the same. The coal for use in this furnace is first ground, sifted, and dried; it is then introduced into a hopper above the furnace, and is fed to the tube-piece by rollers, whilst suitable doors applied to the tube-piece renders the admission of the amount of coal and air easy of regulation, according to the requirements of the furnace at different stages. The several joints, and the chamber itself, are cooled down by the circulation of water about them. The revolving chamber makes from 10 to 15 revolutions per minute. The cinder or working bottom of the furnace is prepared after the same manner as that of the Danks' furnace, where, after the withdrawal of a charge, the furnace is fettled by throwing in lumps of cinder, which embed themselves in the fluid cinder remaining in the chamber.

The conduct of the puddling operation is pursued in a similar manner to that observed with the Danks' furnace, and the proportion of coal-dust is adjusted so that it shall all be consumed, without any sensible portion falling down and mixing with the metal under manipulation. A very high and regular temperature is attainable in this furnace, since the combustion of the coal commences immediately it enters the heated furnace.

173. Pernot Furnace.—This is a regenerative gas furnace with a revolving circular hearth, standing at an angle of 5° or 6° with the horizontal plane. The hearth is mounted upon a carriage, in the centre of which is a socket which receives a pivot, around which the hearth revolves, the pivot itself being attached to the under side of the cast-iron segments, which, bolted together and encircled by a strong wrought-iron hoop, form the bottom of the hearth. In addition to the central pivot, the hearth is supported upon the carriage by rollers which are attached to the bed, and these wheels run in a roller path on the table of the carriage as the hearth revolves. The carriage itself runs upon four wheels, which travel along a suitable road, so that the furnace hearth can be drawn out from beneath the roof; and after any necessary repairs, etc., have been effected, the hearth can be again run under the roof of the furnace, and the whole is again ready for work, having suffered but little delay. The hearth is revolved at the rate of from 5 to 6 revolutions per minute, by means of a worm and worm-wheel. The worm-wheel is fixed to the circumference of the ring carrying the roller bearings of the hearth, and into this gears the worm, which is itself driven by a small engine.

The iron plates and castings, forming the bottom of the furnace hearth, are covered to a depth of about two inches with iron-ore and puddling furnace cinder. The hearth, after being thus fettled, is then run under the roof, the temperature is raised and the fettling melted, after which the interstices thus left are filled up with broken cinder.

From 15 to 20 cwt. of pig is then charged upon the hearth, where it quickly melts down, the molten metal standing at the lower side, and so only covers about one-half of the surface of the inclined hearth. Hence, as the hearth revolves, the fluid metal constantly stands at the lowest level, but a film or thin layer of metal always adheres to the bottom, and is carried round with it, exposing, as it passes through the higher positions, a large surface of metal for atmospheric oxidation. The oxide so formed, as the hearth continues to revolve, passes in its turn beneath, and reacts upon the molten metal at the lowest part of the bed, and the charge thus rapidly comes to nature. The balling has to be effected by hand in the usual manner, and at the lowest point of the hearth. The working off of this weight of charge, including shingling or squeezing of the puddled balls, occupies about two hours. The heating arrangements are carried on in the manner usually pursued with regenerative gas furnaces.

174. Utilization of Waste Heat of the Puddling Furnace.—The flame and gases escaping from puddling and reheating furnaces, except those arranged on the regenerative principle, carry away a very large amount of heat, and, accordingly, boilers and hot blast stoves have been interposed in the course of the current of heated gases, between the furnace and the point where the gases escape into the atmosphere, which thus absorb and utilize a portion of the excess of heat which they carry away. An arrangement of this character is that in which the flame and gases pass through the flue of a vertical boiler forming part of the stack; and another arrangement is where the products of combustion pass under a boiler placed on the same level as the puddling furnace.

CHAPTER IX.

THE FORGE AND ROLLING MILLS.

175. Mechanical Treatment of the Puddled Ball.—The puddled ball, as it is withdrawn from the puddling furnace, consists of a spongy mass of malleable iron, of which the particles are imperfectly welded together, and intermixed with much tap cinder, for the expulsion of this latter and the consolidation of the metal, the puddled balls from the furnace are transferred, while still at a welding heat, to *shingling* or *blooming* machines, where the ball is fashioned into oblong slabs called *blooms*, which blooms still retain sufficient heat to permit of their being drawn into rough bars known as *puddled bars*, by passing them through grooved puddling rolls. The operations to this stage are conducted in the *forge*, the subsequent treatment of cutting up, piling, welding, and rerolling for merchant iron, etc., being conducted in the *mill*.

The machines for compressing or working the puddled balls are of two classes, according as the force applied is concussive or compressive; to the former belong the various types of hammer, to the latter belong the class of squeezers.

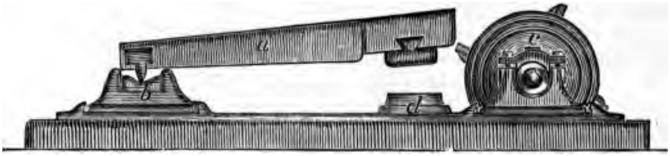

Fig. 43.—Shingling Hammer or Helve.

176. Shingling.—Of the numerous appliances for shingling the puddled ball, amongst the oldest is the shingling hammer or *helve*, sketched, fig. 43, in which an arm or lever *a* is supported at one extremity upon a pivot bearing *b*; the opposite extremity forming the head being lifted by cams upon a revolving wheel *c*, and allowed to fall by its own weight, through a lift of from 16 to 20 inches, upon the puddled ball placed upon the anvil *d*. The helves are made of several tons in weight, and make from 70 to 100 strokes per minute. The variety known as the *belly helve*, in which the cam is placed below the floor, and acts upon the lever about midway between the head and the fulcrum, gives more space around the anvil than the first description.

Steam hammers are employed for shingling in many of the newer works, replacing the older helve and tilt hammer, the power of adjusting the blow to the condition of the bloom, which is possessed by the steam hammer being especially desirable, while the helve always delivers the same weight of blow under all conditions of the bloom. The steam hammer consists of an inverted steam cylinder *a*, supported upon the standards *c*, *c*, and fitted with a piston, with its connected piston-rod passing through a packing in the lower cylinder cover; the extremity of the piston-rod is attached to the hammer block or *tup* *b*, which moves between vertical guides on the standards *c*, *c*. Steam hammers are called *single* or *double* acting, according as the steam is only applied on the under side of the piston for lifting the hammer head with the piston, which is then allowed to fall by its own gravitation upon the work placed on the anvil, or as the steam acts both in lifting the hammer head with the piston, and also in forcing it down upon the work; in the latter case the acceleration of the falling head is increased by the pressure of the steam above the piston. The puddled ball is placed upon the anvil *d*, the foundations for which in the heavier hammers are upwards of 100 tons in weight. The workman gives motion to the hammer by moving the handle *e*, by which steam is admitted from the boiler to the cylinder *a*, through a suitable slide valve; and the shingler, whose legs and feet are faced with sheet-iron casings, and his face protected by an iron gauze, moves the ball on the anvil between each stroke of the hammer, showers of slag and scoriae being ejected from the puddled ball at the first few strokes of the hammer.

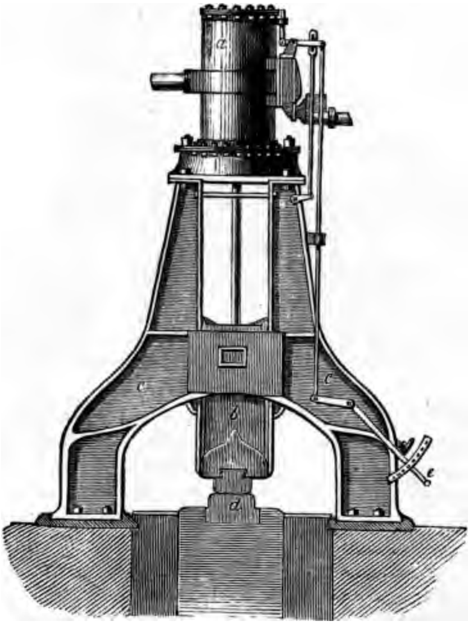

Fig. 44.—25-Ton Steam Hammer.

In Condie's hammer the piston is fixed, and the cylinder carrying the hammer head, block, or tup, moves up and down between vertical guides at each stroke of the hammer.

Squeezers are of various forms. The *alligator* or *crocodile squeezer* consists of a pair of jaws, the lower of which is fixed, while the upper one is opened and closed upon it by a crank and connecting rod, receiving their motion either direct from an engine, or through a heavy fly-wheel connected therewith; the upper or movable jaw is sometimes serrated so as to take better hold of the puddled ball, which is first inserted at the wide end of the jaws, and as its size is diminished from the welding together of its particles and expulsion of the liquid slag, it is rolled by the shingler to the back part of the jaws, where it becomes more consolidated from the greater pressure applied. In some arrangements of this apparatus the squeezer is made double, that is, having a pair of jaws on each side of the centre or fulcrum, as in fig. 45.

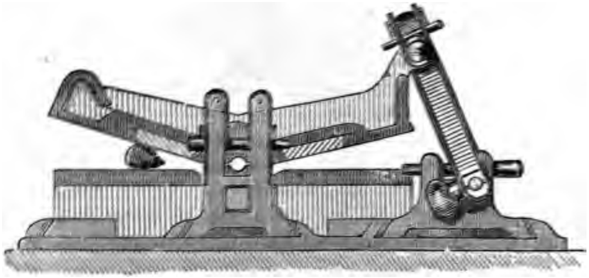

Fig. 45.—DOUBLE SQUEEZER.

The horizontal squeezer consists of a revolving box *a* projecting about 2 feet above the surface of the masonry in which the machine rests, and is placed eccentrically with regard to an outer fixed box *b* embedded in the masonry; thus the ball introduced at the widest part *d*, is carried round by the rotation of *a* from the larger to the smaller portion *e*, where it emerges as a puddled bloom ready for the rolls; motion is imparted to the inner or revolving box from a bevel wheel and pinion beneath the apparatus.

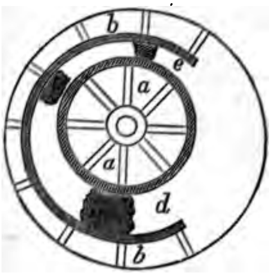

Fig. 46.—HORIZONTAL ROTARY SQUEEZER.

Of the *vertical* squeezers, the most perfect is that of Mr. Brown, which is capable of doing a large amount of work; but the difficulty of maintaining it in working order has prevented its extensive adoption. The squeezer consists of a series of rollers *b*, *b*, shaped as in the accompanying figure, the journals at their extremities resting in bearings in cast-iron frames or standards A, A, they are driven by spur gearing as shown, and by means of the screws *l, l, l* the rolls can be set at any distance apart. A ball *a* (fig. 47), introduced at the top is gradually compressed between the rollers as it is carried downwards, where the bloom falls on a Jacob's ladder, and

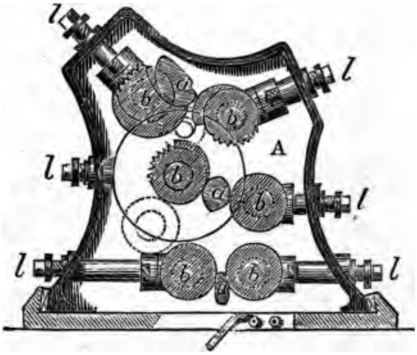

Fig. 47.—Brown's Squeezer, for Squeezing Puddled Balls

is conveyed to the puddle rolls. The figure shows the machine with rollers, to give the ball three compressions, but by inserting other rolls the ball is made to receive a greater or less number of compressions before reaching the bottom of the machine.

177. Rolling Mills.—The shingled bloom, if intended for the production of merchant iron or other bars, is passed while still at a high temperature to the puddle rolls, or, as it is called, the *forge train* or *mill*, where it is rolled into bars some 16 feet in length and 3 inches wide by $\frac{3}{4}$ inch thick, called then *puddled bars*, or if intended for plates or sheets, the bars are made from 6 to 15 inches in width. The forge train consists of two pairs of cast-iron rolls of from 15 to 18 inches in diameter, placed in one line. The left hand pair, called *roughing rolls*, have turned on their surfaces a number of angular or Λ form grooves, diminishing in depth from left to right, and in order to better seize hold of the bar or bloom on its entry between the rolls, the surface of the grooves is usually roughened. In the right hand pair or *finishing rolls*, the grooves, instead of being angular are flat, as shown in the following sketch; the

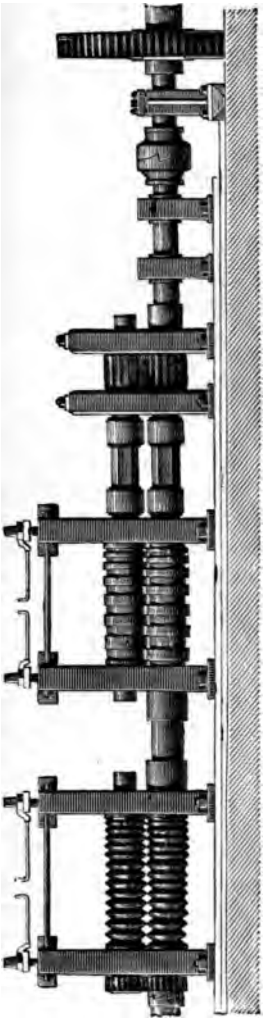

Fig. 48.—Forge Train or Mill, for Rolling Puddled Bars.

grooves in the top and bottom rolls of each set coming together, and jointly producing the section of the finished bar. The two rolls of each pair revolve at the same speed, which in the roughing rolls is from 60 to 75 revolutions per minute, and in the finishing rolls, 80 to 100 revolutions per minute; the bottom roll is connected directly to the steam-engine, while the top one is driven by a spur wheel gearing into a wheel of the same size on the lower roll, the distance apart of the rolls being regulated by the screws passing through nuts in the top of the standards or *housings.*

The bloom is first inserted into the extreme left hand groove of the roughing rolls, and the slab so obtained is returned over the top of the rolls for insertion into the next groove towards the right, unless the rolls are provided with a reversing motion for altering the direction of rotation at each passage of the bar, when it may be introduced into the next groove without drawing it over the rolls. The bloom is passed in this manner from left to right through both series of rolls, the bar so produced being known as *puddled bar*, or No. 1 iron; for conversion into No. 2, or merchant iron, it requires further working, for which pur pose the puddled bar is cut into lengths, piled, reheated, and again rolled. A *pile* consists of a number of bars arranged so as to form a pile or stack, of from 2 to 3 feet in length, and from 6 to 8 inches square, the pieces forming it being arranged so as always to break joint; the pile so formed is held together by a band of iron, and the mass is raised to a welding heat in a reheating or blooming furnace, when it is again passed through grooved rolls, in the rolling mill, similar to those last described, whereby the pressure of the rolls welds the bars into one mass, at the same time reducing its section and drawing it out in length; the rolling is continued until the bar has assumed the required dimensions, or has become so far cooled as to require reheating before rolling further. For No. 3 iron, this process of piling, reheating, and rolling is again repeated, and so on for the higher qualities. Sometimes the welding is effected partly by hammering and is finished only in the rolls.

The *mill train* in two-high mills consists of two stands or pairs of rolls, like the forge mill already described, but in the mill rolls the lower of the left hand or *roughing rolls* is coupled to the lower roll of the right hand or *finishing rolls*, by two cast-iron coupling boxes* and a spindle or breaking-piece, the last mentioned being so called owing to its being the weakest point of the train, and it is expected to break before any other more important part of the mill gives way, when the rolls meet with any unusual obstacle. The upper rolls are coupled together in like manner, except in plate or sheet-mills, where the upper roll of the finishing pair runs loose, and is only driven by the grip of the work as it is driven between the pair by the adhesion of the lower roll. Also in plate or sheet-mills the top roughing roll is always slightly overbalanced, that is, the bearers which carry the journals (necks) of this roll, rest upon vertical bars connected with a system of levers and a large balance weight placed below the level of the mill floor. In this manner the top roll is kept constantly in contact with the screws, or apparatus for regulating the distance apart of the rolls, and for feeding down the same as the slab under operation becomes thinner and thinner after each passage between the rolls.

* Greenwood, *Steel and Iron.*

For rolling rails, bars, rods, strips, angles, sections, etc., the rolls are variously grooved according to the section to be produced; whilst the smaller mills are fitted with "*guides*" for directing the work straight into the grooves, and preventing any twisting of the section as it leaves the rolls; also with "*stripping-plates*" for clearing the bars from the grooves in the bottom roll as the bars pass out from the rolls, thus preventing the collaring or wrapping of the work around the lower roll. Various other appliances are arranged for receiving the work, at the back and front of the rolls as it issues from the same, and lastly tackle is fitted to the mill, for elevating the work and returning it over the rolls in non-reversing mills, etc.

For plate rolling, instead of grooved finishing rolls, plain cylinders are employed, the pile being built up in a special manner, and passed through the rolls, first in one direction, and then in a direction at right angles to the former, so as to widen out the plate and render the plate more uniform in strength in the two directions. In mills for rolling armour plates and other heavy work, in order to avoid the difficulty of returning the work over the rolls, they are always fitted with reversing gear, by which the rolls can be made to rotate in the opposite direction; but, instead of reversing the rolls in mills for small light work, running at a high velocity, the *three high rolls* have been adopted, in which three rolls are employed, the centre one being driven from the engine, while the top and bottom ones are driven from the middle one by spur gearing; in this manner the work may be passed from the one side between the middle and the top roll, and returned back between the middle and lower roll; while for raising the work from the lower to the higher level, or *vice versâ*, as required at each passage of the work, a lift moving in vertical guides, and balanced by a counterweight, is placed in front at each side of the rolls, actuated either by a lever, a single acting engine, or a hydraulic cylinder and ram.

In the manufacture of the *slit rods* used for wire drawing and in nail making, a sheet of metal is cut into rods of square or rectangular section, by passing it through special rolls, on which collars are formed, either by suitably grooving the rolls or placing on them steel discs separated by stops, the collar on one roll working into the space on the opposite roll, but still leaving sufficient space between the periphery of the collar and the bottom of the groove for the rod to pass through; in this manner the rolls form a kind of compound shearing or clipping machine, by which the sheet is divided into a number of rods.

In rail rolling, the top and bottom slabs of the pile are formed of No. 2 iron, between which are placed puddle bars; the pile so formed is heated, welded by hammering, and then rolled as in the previous cases, except that the rolls are grooved so as to finally produce the section of the finished rail, and the rolling is so conducted that the top and bottom plates of the rail pile are made into the heads or part of the rail subject to most wear. The rail so produced is then cut while hot to its proper length, by a saw running at a high velocity.

178. **Low Moor Iron.**—For the production of the best qualities of Yorkshire iron, as that of Low Moor, Farnley, and Bowling, a special method of treatment is pursued; the pig, as already noted, is first refined, broken into small pieces, and then puddled in small charges, with the employment of a somewhat higher temperature than ordinary; the puddled balls produced are shingled under a helve hammer, and formed into plates or slabs called *stampings*, of 1½ to 2½ inches in thickness, and 10 or 12 inches square, which slabs are then broken by the *guillotine* (a weight which is raised up and allowed to fall from a considerable height). The pieces so obtained are carefully assorted and classed according to the fracture, to be used for the production of hard or softer varieties of iron. The selected slabs are then piled together, heated, and welded under the hammer, the masses produced being reheated and rehammered two or three times, the rolls being here only employed in the last stages for giving to the bars their proper shape and section.

In the manufacture of axles, shafts, and bars of large size, the iron is *faggoted;* that is, a number of small bars are bound together into a bundle, which is then heated in the reheating furnace and welded into one mass under the hammer, when if their form allow, they are finished by rolling.

179. Rolling of Steel Ingots.—The forge operations of squeezing or shingling, passing through the puddle rolls, with the cutting-up, piling, reheating, and rewelding of the bars in the mill for the production of plates, rails, and merchant iron, as cited in the preceding articles, are confined to the treatment of malleable iron; since with steel or ingot-iron, the metal is cast into ingots which are practically free from the slag or cinder which accompanies the puddled ball, and the squeezing and shingling operations are therefore unnecessary. Steel is also void of the lamination and fibre characteristic of puddled bars, and does not require therefore the careful piling, welding, and rolling in different directions so as to get an approximately equal strength both with, and across the fibre. The forge operations described for the working of malleable iron are thus both unnecessary and undesirable in the working of steel or ingot iron. Moreover, steel ingots can always be cast of sufficient weight to make the desired bar, section, or plate, without any building up or welding together of two or more pieces. The treatment of steel is therefore confined to the reheating of the cast ingots as received from the steel melting department, and their treatment in the mill by the hammers for the production of blooms, slabs, billets, etc., and the rolling of these in the mill-train into rails, bars, sections, plates, etc.

The practice of *hammering steel ingots* into blooms, slabs, billets, etc., before rolling into rails, plates, bars, etc., is being gradually discontinued, when the steel ingots, if not treated in the soaking pit arrangement (p. 201), are reheated in the mill furnace and passed at once direct to powerful mills known as "*cogging mills,*" where they are rolled into blooms, etc., which are then subsequently returned to the reheating furnace before passing to the mills for rolling into sections, bars, etc. In the production of rails, the blooms are usually sufficiently hot when they leave the cogging mill, to admit of being rolled straight off in the rail-mill into sufficiently long single lengths, and of their being cut up under the hot saw into three or even four 30 feet lengths of rail, thus reducing the considerable amount of waste or scrap arising from crop ends, etc., which are produced when rails are rolled in single lengths.

For the production of *steel-tyres* the ingots are cast cheese-shaped, that is, shorter and of greater diameter than the usual form of steel ingot as cast for general use, and each ingot is made of the weight required for a single tyre. Such ingots after reheating, are flattened down under the hammer to about half their thickness, after which the centre is punched out under the same hammer and at the same heat; whereupon the ring so produced is opened out upon the side-beak of the anvil of the hammers which are engaged upon this work. In this manner a *tyre-ring*, roughed to the section of the tyre, and having a hole about 20 inches in diameter through its centre, is produced. This ring is then reheated, opened out, and finished to the required section and diameter either in a horizontal mill, or, as is now more usual, in open-end rolls. The tyre so produced is finally levelled, made perfectly round and of the exact diameter required, by setting and stretching on a centre mandril or suitable blocks upon a flat straightening table.

The mill hammers for the production of blooms, slabs, billets, etc., from steel ingots, are, like the mills and machinery generally, usually of a heavier and more powerful type than the shingling hammers already described. Double-acting steam hammers with a wrought-iron framing of box section, and having a falling tup of 8 tons, with a stroke of 7 to 9 feet is a usual type, but for exceptional work even much heavier and larger hammers are employed; but the operation of cogging or rolling steel ingots direct, without the intervention of the steam hammer, is becoming more general.

The mill-rolls for the rolling of steel do not differ very materially from the corresponding rolling mills employed in the treatment of the piles of malleable iron, except that they are generally much longer, stronger and heavier in all their details.

180. Rolling-mill Engines.—These are often of great power, and in the larger mills are worked in pairs. Non-condensing, high-pressure, non-reversing, vertical or horizontal engines, with heavy fly-wheels, are most prevalent for driving the smaller mills, rolling merchant and guide-iron in two or three high mills. Numerous examples are also at work of condensing engines of the same type driving similar mills; but for driving the larger mills working upon heavy sections, rails, plates, etc., *reversing* mills prevail. In these either the engine itself, which must be without fly-wheel, is reversed at each passage of the work, or, instead of reversing the engine, the rolls themselves may be reversed by an arrangement of friction, or hydraulic clutch, or by differential gearing; in the latter cases the engine itself runs constantly in the one direction; but the reversing engine is the one now more generally adopted.

When reversing engines are employed, either the crank-shaft of the engine is in line with the rolls, and is coupled direct to them by a suitable clutch, or else, there is a pinion on the crank-shaft which gears into a wheel on the second motion shaft of the engine, in which case the second motion shaft is in line with the rolls, and drives them through a claw clutch. Reversing mill-engines are made of very large dimensions, and are usually either high-pressure and non-condensing, or are compound engines. In either case they are without fly-wheel, but are necessarily provided with a link-motion for effecting the rapid reversal of the engine and mill, whilst, to prevent the driver from too suddenly stopping and reversing the direction of the rotation of the engine after each passage of the work, the engines are fitted with a small water cylinder, or cataract arrangement, fixed between the pair of engines, and through which the reversing lever of the engines works.

181. **Mill Machinery.**—Other necessary accessories of the rolling mill are *crocodile*, *guillotine*, or other shears, for cutting off the crop or waste-ends of rails, puddled, finished, or other bars, etc.; whilst in the case of heavy sections, rails, etc., which are cut to length immediately they leave the rolls and whilst still at a red heat, a large circular saw, revolving at the rate of from 800 to 1200 revolutions per minute, is usually employed. The rail is drawn in front of the saw, whilst the saw, which hangs in a swinging frame, worked in and out by a rack and pinion, is advanced against the rail, and rapidly cuts it through, leaving a clean square end. In the plate and sheet mill, heavy shears are arranged for cutting the plates to dimensions and to shape, and lastly, but more especially in steel works, a testing machine for

indicating the tensile strengths and ductility of test samples of the metal, is absolutely necessary to ensure conformity with engineers' specifications.

182. Reheating Furnaces.—The furnaces employed for reheating the blooms, billets, piles, or stamps of malleable iron, described in the last paragraphs, and the ingots, blooms, billets, slabs, etc., of steel, are of several classes: (1), the *open fire*, used where malleable iron is produced in the finery; (2), the *hollow fire*, as used in the South Wales process; (3), the *reverberatory reheating* or *balling furnace* most generally adopted; and (4), the *soaking pits* of Mr. Gjers, which utilize the initial and latent heat of the fluid metal in recently cast steel ingots, in preparing the same for the rolling mill. The furnaces of the first two types have been described under the finery and South Wales processes respectively (p. 153); and of the third, or reverberatory type, there are two classes, one of which burns coal and solid fuels directly upon its own grate, while the other is heated by the combustion of gaseous fuels.

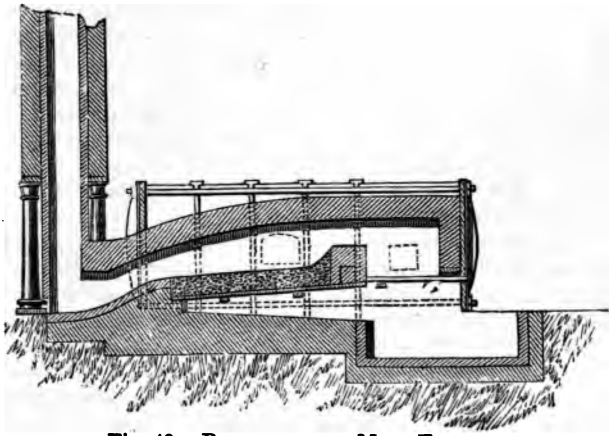

Fig. 49.—Reheating or Mill Furnace.

The *reheating* or *mill furnace*, in which coal is employed as the fuel, resembles the puddling furnace in external appearance and form, the essential difference between the two consisting in the smaller proportion of the fire-grate to the hearth, and in the construction of the bed of the mill furnace. The bed of the reheating furnace is first lined with fire-brick, and is then coated with sand rammed well in while moist. The bed slopes uniformly from the fire-bridge to the flue, so that the *slag* or *flue-cinder*, produced by the combination of the sand with the oxide of iron or scale formed by the oxidation of the metal in the furnace, may run down to the bottom of the flue, and there escape through a tap-hole made for that purpose. A small fire is often maintained outside the stack and in front of the tap-hole, for preventing any stoppage by the consolidation of the cinder. Like the puddling furnace, the stoking door of the mill furnace is stopped with coal, and the draught is controlled by a stack surmounted by a damper; in furnaces for heating bars of ordinary sizes the roof is kept very low, but its height is controlled by the special conditions of the work. In furnaces for heating large plates and long heavy bars, it is usual to place a second fireplace near the flue, and at right angles to the principal one. The furnace is supported externally by cast-iron plates and backstaves, connected together by tie rods over the top of the furnace.

Reheating or mill furnaces *using gaseous fuel* have been extensively introduced, instead of the above form. In the last described furnace, the solid fuel is burnt by the admission of air to the grate-bars, so that the heating power is chiefly derived from the sensible heat of the flame and gases as they pass from the bars over the fire-bridge and hearth of the furnace to the stack, whereas in the gas furnaces, the combustion of the gases commences at the fire-bridge, and is only completed on the hearth itself. With the use of gas, as already mentioned, a better, more uniform, and more easily controlled heat is ensured, with a less consumption of fuel and less waste of metal from oxidation.

The gases required for combustion may be generated either in separate producers, quite independent of, and isolated from the furnaces themselves, as in the original arrangements of the late Sir William Siemens, or like the Bicheroux, Ponsard, Casson, Boëtius, and other furnaces, the producer or gas generator may be directly connected with, or form part of the same structure as the furnace itself.

The *Siemens reheating* or *mill furnace* is a regenerative gas furnace, of which the gas-producers have been already described (page 62), whilst the regenerators are the same as those described (fig. 55, page 236). The furnace itself resembles in external appearance and form either the ordinary puddling, or the Siemens' steel-melting furnace, but it is fitted with one, two, three, or four working doors, according to the power of the furnace and the requirements of the work under operation; while it differs also from the melting furnace (fig. 55, page 236) in having smaller regenerators, and instead of the dipping roof usual in the melting furnace, the heating furnace has a low, nearly flat, arched roof, although the height of this varies with the size of the work to be heated. The bed or hearth of the reheating furnace is simply prepared with 10 or 12 inches of sand, spread over the fire-brick lining of the bed-plates of the furnace, and it slopes only slightly from front to back towards the tap-hole, which is situated at the centre of the back side of the furnace. The tap-hole is only required at irregular intervals, for the withdrawal of the cinder, which collects on the hearth during the working of the furnace. The two ends of the furnace are built quite symmetrically as to the regenerators, air and gas ports, whilst the manner of working the furnace is precisely the same as that described on page 237.

The Siemens regenerative reheating furnace, although originally designed to be worked in conjunction with the Siemens producers, can, and is very frequently, worked with the Wilson or other gas generating apparatus.

The *Ponsard regenerative reheating furnace* works with its own gas producer, which is similar in construction to the Siemens producer, but it is erected below the floor level, and forms a part of the furnace structure itself. The gases thus rise direct from the producer to the fire-bridge or ports of the fnrnace, the supply of gas being controlled simply by a damper placed in the flue, between the producer and the furnace hearth. This furnace is fitted with but one regenerator, or, as it is called, "recuperator." This is a chamber filled with an arrangement of solid and hollow bricks, whereby the solid bricks form a series of vertical passages through which the waste gases from the furnace descend on their way to the stack; whilst the hollow bricks are arranged between these so as to form transverse passages which communicate with one another, but not with the vertical passages through which the waste gases pass. In this manner, whilst the waste gases pass downward through the vertical passages, and thus heat the recuperator, at the same time the cold air enters at the bottom of the chamber, and ascends through the numerous transverse passages on its way to the furnace, which it enters at a temperature of about 500° C. This recuperator is therefore continuous or non-intermittent in its action, and the heated air always enters the furnace at the producer end, whilst the waste gases escape from the opposite end of the furnace and pass away through the recuperator to the stack, and no reversal of the current is necessary. It will be observed, also, that only the air for combustion is heated, whereas in the Siemens furnace both the gas and air are so heated.

The *Bicheroux, Casson-Bicheroux, and Boëtius* furnaces are each gas furnaces without regenerators, and burn the gases direct from their own producer, which occupies the place of the fire-grate in the ordinary coal furnace. In these furnaces arrangements are only made for raising the initial temperature of the atmospheric air, and this to a temperature which is below that attainable in the Siemens furnaces.

In the Bicheroux furnace the air is drawn from the flue end of the furnace, and is heated by circulating through a broad, flat and shallow flue, built beneath the heated hearth of the furnace, before it meets with the producer gases for combustion at the fire-bridge.

In the Casson-Bicheroux furnace the air is heated by circulating it beneath the ash-pit, around the sides, and through the back of the producer (page 66), before it is delivered in a broad stream, above and behind the gases from the producer. The producer may be built either close to and forming part of the furnace, or it can be built at a convenient distance behind the furnace, the supply of gas being regulated by a damper in the flue between the producer and the furnace.

The Boëtius furnace heats the air by circulating it through the sides and over the roof of the producer, before it finds admission to the fire-bridge of the furnace.

In Austria and Hungary a gas furnace using wood as the fuel, has three hearths between the *generator* and the stack. The first hearth, or that nearest to the generator, is heated by the sensible heat of the gases therefrom, and is used as a *reheating furnace;* while in the second or puddling hearth, the combustion of the gas is effected by the introduction of air over the fire-bridge; and in the third, which is heated by the gases as they pass from the puddling-hearth to the stack, the pig-iron is placed for preliminary heating before moving it on to the puddling-hearth.

The *cinder* or *mill furnace slag* produced in these reheating furnaces is essentially a tribasic ferrous silicate, containing from 50 to 60 per cent. of ferrous oxide, equal to from 45 to 50 per cent. of metallic iron; it also contains about 30 per cent. of silica, and smaller proportions of ferric oxide, manganous oxide, alumina, lime, magnesia, sulphur, and phosphoric anhydride.

The *loss of metal in the conversion of pig-iron into bars* of malleable iron, varies with the kind of pig operated upon; with the skill of the workman, and with the kind of iron produced, that is, upon the number of reheatings to which it is subjected. In Staffordshire the loss averages about 25 per cent. of the pig-iron, and in South Wales it is somewhat greater.

183. Soaking Pits.—These pits were first successfully used by Mr. Gjers, to avoid the necessity of reheating Bessemer steel ingots, intended for rolling into rails. The arrangement consists of a group of pits or vertical chambers, which are built below the floor level, in a compact rectangular block of brickwork, each chamber measuring about 3 inches more in width, and from 6 to 18 inches more in depth than the steel ingot which it is intended to receive. Each chamber is covered with its own movable cover-lid of firebrick or of fireclay tiles, and the whole group of pits is controlled by a crane for quickly inserting and withdrawing the ingots, and delivering the same to the hammers or rolls, as the case may be.

The soaking pit arrangement is only applicable to the treatment of steel ingots. These ingots present on removal from the moulds, within a few minutes of the metal being cast, an external skin at a red heat only, while the interior of the ingot is probably still in a fluid condition, and altogether too hot to pass through the rolls. But by placing such ingots, each in a separate firebrick chamber or pit previously heated to redness, and then closely covering the same, the initial heat of the ingot, together with the latent heat of the fluid metal in its interior, and which becomes sensible as the metal solidifies, soaks or distributes itself uniformly throughout the whole mass of the metal. After remaining in the pit for from twenty to thirty minutes, or upwards, according to the size of the ingot, such an ingot will present on withdrawal a skin which is sensibly hotter than when it was first inserted into the pit, and the ingot itself is also more uniformly heated throughout, whilst at the same time it is quite hot enough for treatment either under the hammer or in the rolls, and this result has obviously been attained without the expenditure of any fuel for reheating purposes.

In putting these pits to work it is necessary, therefore, to first thoroughly dry the brickwork, and then to insert ingots into the several chambers until the brickwork has all become heated to redness, after which they are ready for regular work, and will work continuously so long as the supply of ingots is maintained. The steel ingots for insertion into these pits should be allowed to stand in the moulds in which they are cast only sufficiently long to bear lifting with safety, when they should be removed and transferred as quickly as possible to the heated soaking pits, to stand therein as stated above, until ready for the rolls.

During the time the ingots are in the pits a quantity of gas, chiefly hydrogen, nitrogen, and carbonic oxide, exudes from the same, which fills the chambers, and burns in small quantities around the edges of the covers. The gas exuded takes fire immediately the covers are removed for the withdrawal of the ingots, but it has served during the soaking process to fill the chambers with a non-oxidizing atmosphere, and the ingots do not, therefore, scale or waste to the same degree, as occurs in the ordinary reheating operation.

CHAPTER X.

STEEL.

Steel is a combination of iron with from 0·1 per cent. to 1·8 per cent. of carbon, or, as defined by Mr Holley in a lecture before the Stevens Institute, U.S., steel is an alloy of iron which is cast in a fluid state into a malleable ingot, has a bluish-grey colour, with a tinge of brown; in cast-steel, it is usually considered that the *bluer* the shade in colour the better the metal; when hardened, it is whiter than in its soft condition. The *fracture* of a steel ingot of a *hard* temper should show a shining silky appearance, not dull and leaden looking, nor containing bright specs embedded in a dull matrix. Steel is void of the fibre so characteristic of wrought or bar iron; its *specific gravity* is from 7·6224 to 7·8131 (Karsten); it is softer than speigeleisen but harder than bar-iron; is very malleable when hot, but requires working at a lower heat than wrought-iron, with the exercise of greater care than is necessary with the latter; it expands less than cast-iron under the influence of heat and can be welded at a lower temperature than suffices for malleable iron, requiring, however greater attention that the surfaces be freed from scale or oxide by the use of borax instead of the sand used in welding wrought-iron. Its *melting point*, about 1800° C., is between that of pig-iron and of malleable iron; it is less easily magnetised, but its magnetism is more permanent than is that of pure iron; it is also less oxidizable on exposure to air and moisture than is malleable iron. The *tenacity* of steel varies much with the temper; soft Bessemer or Siemens steel will break under a load of from 24 to 26 tons per square inch of section, while the steel used for engineers' tools requires a force of 70 tons or upwards per square inch to break it. The *power of elongating* before fracture in the milder varieties is not inferior to that of malleable iron; strips of steel boiler plates $\frac{3}{8}$ inch thick and 3 inches wide, may have a $\frac{5}{8}$ inch hole drifted to 2½ inches in diameter without cracking the plate; while in *elasticity*, steel is superior to malleable iron. The strength and ductility of steel are improved by hammering, rolling, and wire-drawing, if these operations be conducted at suitable temperatures. The most characteristic and at the same time most important quality for many purposes to which steel is applied, is the facility with which the harder tempers may be *hardened* by heating and suddenly cooling, as by immersion of the heated metal in cold water, etc.; the more quickly the cooling is effected, the harder does the steel become; if plunged into oil, which does not act so rapidly in cooling the metal, it is but slightly hardened, but its tenacity is sensibly increased; while by immersion in mercury, or other good conductor of heat, the steel is rendered intensely hard. The metal after hardening is *slightly increased in volume*, and its specific gravity is accordingly reduced, the specific gravity in the hardened state varying from 7·55 to 7·75 (Rinman); in its soft or unhardened condition, if treated with hydrocloric acid it leaves a graphitic or carbonaceous residue, while the same steel in its hardened state is wholly dissolved under the like treatment. By heating to redness, and then allowing to cool slowly, *i.e.*, "*annealing*" of hardened steel, it is restored to its original condition of softness and malleability; thus by hardening and subsequently heating to a temperature below redness, and then suddenly cooling by immersion in water when the steel has acquired the desired temperature, it may be obtained of various degrees of hardness, this operation being known as "tempering" the steel, or in the workshops "letting down;" if the surface be polished and this operation of reheating performed with access of air, films of oxide form on the surface of the steel giving rise to a regular succession of colours, as the temperature rises or falls; from these colours the workman determines the temperature or *temper* of his work; the shades which successively appear as the steel is gradually heated are light straw colour, dark straw, golden yellow, brown, purple, violet, and deep blue; the first corresponds to a temperature of about 220°C., giving the hardest temper, such as is required in tempering razors, etc., while deep blue, or the temper given to saws, corresponds to a temperature of about 320° C. Articles of steel that require to be hardened and tempered, are first forged and finished working while in their soft state, and are subsequently hardened and tempered.

ANALYSES OF BESSEMER, SIEMENS, AND CRUCIBLE STEEL.

	Soft Neuberg Bessemer Steel.	Siemens' Steel Plates.	Bessemer Steel Rails.	Steel for Coining Dies.
Carbon,	0·126	0·21	0·313	1·07
Silicon,	0·135	0·047	0·078	0·06
Sulphur,	0·014	0·052	0·076	trace
Phosphorus,	0·060	0·035	0·071	trace
Manganese,	0·158	0·36	0·515	0·12
Copper,	0·112	...	trace	...

As steel approaches in physical characters to the nature of malleable iron on the one hand, or to pig-iron on the other, so the chemical composition tends to similarity with those of these limits. In *mild* steel, the carbon frequently does not exceed 0·1 per cent., malleable iron often containing 0·25 per cent. Steel containing only 0·1 per cent. of carbon may be welded almost as easily as iron, and can be worked under the hammer at nearly the same temperature as is used for malleable iron. The *harder* tempers of steel, containing 1·5 per cent. of carbon, are more brittle, require to be hammered with great care and at a comparatively low temperature, thus approaching towards cast-iron in behaviour. The hardening quality of steel seems to depend upon its state of carburization. Steel containing less than 0·5 per cent. of carbon does not sensibly harden except in very small thin pieces; but the higher the carburization, the lower the temperature at which the steel will harden. Pure iron will not harden even if plunged into mercury. The *coefficient of expansion for heat* is less in steel than in cast-iron, hence the allowance to be made in the moulds for the contraction of steel castings, is a little less than that allowed for the same purpose in the case of cast-iron. Fluid steel possesses the power of *occluding* certain gases, notably of hydrogen, and of again largely liberating the same at the moment of the solidification of the metal; hence steel ingots, especially of the milder tempers, are usually unsound, presenting when fractured an honeycombed, vesicular, or piped structure, of which the small honeycombs or cells are mostly filled with a gas consisting of from 70 to 90 per cent. of hydrogen, with from 10 to 20 per cent. of nitrogen, and but small proportions of carbonic oxide.

Silicon, present to a large extent in certain varieties of pig-iron, occurs but to a very limited amount in steel, the presence of 0·5 per cent. of this element in steel rendering it almost unworkable at a red heat.

Sulphur, *phosphorus*, and *copper* are the great enemies of good steel, 0·05 per cent. of sulphur rendering the metal *brittle* and *red-short*, while 0·1 per cent. of phosphorus is objectionable as tending to render the metal unworkable at ordinary temperatures, *i.e.*, *cold-short*. The effect of phosphorus is also to harden the steel in the same manner, but more rapidly than carbon does. 0·5 per cent. of copper induces *red-shortness* in the steel.

184. Alloys.—Steel alloys itself readily with many other metals. *Copper*, in not too large proportion, alloys readily with steel, with the production of a substance harder than steel, but which is also red-short.

Tungsten alloys with steel in all proportions. The product is said to be harder and more elastic than ordinary steel; it requires, however, considerable care in its production. A special "*tungsten steel*" is prepared which can be cast into the forms required for engineers' tools, and which, without any hammering or forging, can be ground to a fine edge in the usual manner. Such steel is sufficiently hard and durable for the requirements of engineers' tools without any hardening or tempering process.

Manganese, in some form, is now almost universally used in the manufacture of steel; as speigeleisen or other combination of carbon with iron and manganese, its use forms an essential element for the success of the Bessemer process, and it is also said to render the ingots sounder and more free from honeycomb. The action of manganese in improving the quality of steel is by no means determined, for it would not appear to depend upon the formation of an alloy of manganese and steel, since the manganese passes almost wholly into the slag, a small proportion only entering into the composition of the steel; still, that the presence of a small amount of manganese is necessary is shown from the fact, that the steel which has been re-melted without a further addition of manganese (and in which the residue of manganese would be removed in the second slag or flux), is found to be *red-short*, while, if a little manganese be added to the charge in the re-melting, the quality of the metal will not be deteriorated by the second fusion.

Manganese in small proportions hardens steel, increases its strength, but decreases its ductility. Its presence also partially neutralises the cold-shortness induced by the presence of phosphorus in the steel, and also, provided the manganese be not present in excess, it improves the quality of steel, which would otherwise be red-short from the presence of sulphur. Hence the advantages arising from the actual presence of manganese in the finished steel, appear to be principally due to its correction of the evils produced by the presence of impurities, such as sulphur and phosphorus; but its use, as already mentioned, for the expulsion of gases, etc., from the metal during the manufacture of steel by the Siemens, the Bessemer, or other process, is now also universally accepted.

The use of *titanium* in steel is the subject of numerous patents. It is said to give "body" to the steel, that is, the quality of retaining its hardness *without* brittleness after repeatedly reheating; its use is however questionable, and I have been unable to detect titanium in some specimens of the so-called titanic steel. Steel will only alloy with very small proportions of *silver*, and if melted with considerable quantities of silver, the latter almost wholly separates on cooling.

Gold, *platinum*, and *aluminum* alloy readily with steel, though the resulting alloys have had but few practical applications.

Aluminum was once considered to be an essential of the fine Indian steel known as "*Wootz*," which is capable of receiving such a fine damaskeened surface; this view, however, is now discredited.

185. Damaskeening is the name applied to the method of producing the brown colouration and figuration of gun-barrels, sword-blades, etc.; it is produced by the action of various acid solutions on the metal, and is considered to be due to the unequal corrosion or solvent action of the liquid upon the metal, with the deposition of films of carbon, etc., on various parts.

186. Methods for the Production of Steel.—The methods for the production or manufacture of steel may be classed under the following heads:—

I. Methods of *producing steel direct from the ore*, as in the Catalan forge, or by heating rich ores such as the oxides of iron, with carbon or carbonaceous matters either in crucibles or in suitable furnaces.

II. By the *carburization of malleable iron* by solid or gaseous carbonaceous matters, as in the *cementation* process, and in the process for the manufacture of cast-steel in crucibles or other vessels.

III. *Decarburization methods*, which are divisible into the following classes, viz.:—

1. By the partial decarburization of pig-iron in the finery, the puddling furnace, or in other apparatus.
2. By the fusion of pig-iron with oxide of iron, etc., as in the **Uchatius'** process, the **Siemens'** open-hearth direct process, etc.
3. By the fusion of pig-iron with malleable iron, as in the **Siemens-Martin** process.
4. By the **Bessemer** or *pneumatic* process, including also the Basic process.

DIRECT METHODS, OR THE PRODUCTION OF STEEL DIRECT FROM THE ORE.

187. Steel in the Catalan Forge.—The Catalan forge has been already described (p. 145), and it is only requisite, if steel is to be produced instead of malleable iron, that the product be less highly carburized; and for this purpose the inclination of the twyer is diminished, whereby the reduction of the ore is effected more slowly, and the reduced metal is therefore allowed to remain for a greater length of time in contact with the fuel (charcoal), whereby an amount of carbon is introduced into the metal sufficient to give the product the character of *steel.*

This process, as also all those for producing *natural steel,* as practised in Styria, Westphalia, and other parts of the south of Europe, known as the Styrian, Carinthian, and other processes, are rapidly being replaced by the more modern methods of steel manufacture, and will not require further notice.

188. Chenot Process.—This process consists of two stages, viz.:—

1. Fusion of the ore in a particular manner, for the production of a metallic sponge.

2. The fusion of this spongy mass, either with solid hydrocarbons, or after its saturation with liquid hydrocarbons.

The metallic sponge is prepared by breaking the ore into lumps about 30 c.c. in size, which are cemented together by pressing them with about 3 per cent. of resin, and the ore so prepared is mixed with more charcoal than suffices for the removal of the oxygen in the ore. This mixture is introduced into a furnace about 50 feet high, consisting of two vertical retorts contained within a conical covering, vertical flues conducting the gases and flame from the fire along the vertical sides of the retorts; the reduction is completed in from three to five days, when the charge is withdrawn by removing the bars at the bottom of the retorts, and allowing the mass to fall into receivers placed on waggons beneath their lower extremities. The receivers or coolers can be closed so as to prevent the access of air until the mass has cooled down, which may be promoted by circulating water around them. The *metallic sponge,* or pulverulent matter so obtained, is mixed with charcoal powder or solid matters rich in carbon, or saturated with liquid substances rich in carbon but free from sulphur; the mass is then compressed to about two-thirds of its original bulk and melted in crucibles, when the gangue of the ore rises to the top of the melted metal, and is cooled immediately before teeming by throwing in a little sand, when it may be skimmed off. This process has been found unprofitable in Sheffield, since the Chenot charge, though smaller than an ordinary crucible charge, requires the same quantity of coke for its fusion.

189. The Siemens Direct Process.—The late Sir W. Siemens, F.R.S., adopted the principle of his regenerative gas furnace to the production of wrought iron or steel direct from the ore. The furnace now employed is a rotating chamber, or rotator as it is called, which revolves in a vertical plane, and is connected with its own gas producers, as also with two regenerators of the ordinary Siemens construction.

The *rotator*, or revolving cylindrical chamber is of wrought iron, and measures about 10 feet 6 inches in diameter, and 10 feet 6 inches long; it is encircled by two rails which rest upon four anti-friction rollers; and the whole is connected with a small engine and gearing, by which varying speeds of rotation can be communicated to it. The chamber is lined with a basic lining, formed of a single course of firebrick laid on edge over the whole surface of the iron casing, and upon the bricks a working basic lining, or fettling of about 2½ inches in thickness, is made by melting within the rotator itself a mixture of hammer-scale and iron ore.

In the vertical end of the revolving chamber, nearest to the producers, is a circular aperture or throat, through which the gases and air from the producers and the regenerators respectively are admitted to the furnace for combustion, and the annulus in the furnace and around this opening or throat is by preference lined with bauxite or magnesite bricks. In like manner, in the opposite vertical end of the furnace, is a circular charging or working door, placed between the centre and the periphery of the end plate. This door is closed and securely fastened during the time the furnace is revolving. Like the throat end, the end plate around the charging door is also lined with bauxite bricks, since each end is subjected both to the mechanical abrasion of the moving charge as the furnace revolves, as well as to the corrosive action of the slag, and these bricks withstand such action better than ordinary fire-bricks. In the front end of the rotator, and beneath the working door, is the tap-hole by which the slag is tapped out into vessels placed in a cave beneath the rotator.

The two regenerators, with which each furnace or rotator is connected, each serve alternately for heating the air as it passes to the rotator, and then for absorbing the heat from the products of combustion as they leave the chamber, after the ordinary manner of a pair of Siemens' regenerators; and it will be noted, therefore, that it is only the air that is heated by passing through these regenerators, whilst the gas is supplied direct from the producers to the furnace. A brick partition (in the neck or throat that is built between the brickwork of the regenerators and the rotator itself) constitutes the only division between the flue through which the air and producer gases enter, and the exit flue by which the waste gases leave the rotator for the regenerators and the chimney. The velocity with which the gases and air enter direct from the producer, and the regenerators respectively, is sufficient to carry them through the furnace to the working door, before they are drawn back by the draught of the chimney into the exit channels, which, as just described, are at the same end of the chamber as the openings by which the gases and air are introduced.

The furnace or rotator having been heated up during the slow revolution of the chamber, it is then revolved until the open charging door in the front end of the rotator is in its most elevated position. The rotator is then stopped, and the end of a telescopic shoot from the charging hopper, is introduced into the charging door. A slide in the bottom of the hopper being drawn, the charge, consisting of about 20 cwt. of small ore (hæmatite), 12 cwt. of hammer or roll scale, and about 6 cwt. of charcoal (all previously mixed together and raised by a Jacob's ladder, or other suitable arrangement, to the elevated hopper, during the time that the previous charge was being worked off), is now introduced, after which the velocity of rotation is increased, to facilitate the mixture of the charge. Decomposition ensues, and the ferric oxide is reduced to magnetic oxide, which, as it begins to fuse, causes the decomposition to become more violent; at the same time some metallic iron is separated, and a liquid slag is also produced. During this stage the velocity of the rotation is diminished, and the supply of gas is almost entirely shut off, heated air only being admitted as required for the combustion of the gases produced during the decomposition in the rotator of the ore and scale by the carbon of the charge.

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PRODUCTION OF STEEL BY T MALLEABLE IRON.

190. Cementation Process.—The cemen ing process consists in the conversion of bar-ir by the long continued application of a heat appro whiteness, or about 1170°C., to bars of iron embedde charcoal, the whole contained in suitable chests, and k out of contact with the air.

The converting furnace has externally the appearance of an ordinary glass-house furnace; it consists of two stone or fire-brick boxes or troughs N, N, called *pots*, each from 3 feet to 4 feet in width, about the same in depth, and 12 feet in length, and open at their upper surface. These pots are arranged one upon each side of the fire-place C, which runs the full length of the furnace, and are contained within the chamber or vault of fire-brick A, covered in by the arch B; beneath and up the sides of the pots are built a number of transverse and vertical partitions respectively, whereby the space along the length of the pots is divided into a number of transverse and vertical flues, so that the gases and products of combustion from the fire circulate under and around the boxes before obtaining access to the flues D,D, and by the short chimneys E,E, with the interior of the dome F, which surmounts and encloses the whole. There are usually three of the short chimneys E along each side of the vault. G is a man-hole in the brick end of the chamber or vault, large enough to admit of the entrance of a man to charge of gas and air in larger quantities, and the speed of rotation is at the same time increased. When the reduction is completed the slower speed of rotation is resumed, and the precipitated or reduced iron is collected into five or six balls. The rotator is now stopped with the tap-hole and charging door at their lowest points, when the highly basic slag or cinder produced by the process is tapped out in the manner already mentioned into suitable slag tubs or barrows standing beneath the tap hole. After the slag has been tapped out the balls of spongy malleable or steely iron are then drawn from the rotator on to bogies standing in front of the door, and are conveyed to the hammers or squeezers to be shingled or squeezed in the ordinary manner, for the production of blooms corresponding to the puddled blooms from the puddling process; or if it be intended to use the product for the manufacture of steel in the open-hearth furnace, then either the rotator balls or the shingled blooms, are transferred at once and whilst still hot, to the open-hearth furnace, where they are melted along with the other ordinary materials of the furnace charge.

The process of reduction lasts about three hours, it is attended with a very large economy in fuel, and but a very small amount of manual labour is required for the conduct of the process. There is, however, a considerable loss of iron in the slags, but the process for this reason effects a very large elimination of phosphorus from the iron produced by this process from phosphoric ores, such as those of Northamptonshire.

It is necessary that the surface of the lining of the revolving chamber be not quite regular and smooth, or otherwise the charge simply slides around as the rotator revolves, without turning over fresh portions of the mixture of ore and charcoal to the action of the flame, and of the reducing influence of the furnace gases. The irregularities in the surface of the lining also serve to break up the charge for balling in the later stages of the process. In the more recent arrangements for producing this irregularity of surface, four pipes are carried through the furnace from back to front, between the shell and the firebrick lining, and beneath the fettling. Upon each of these pipes are two elbows or bends which stand vertically above the general level of the fettling. These elbows are themselves protected from the heat and abrasion of the moving charge, by covering them over with brickwork and fettling, like the body of the furnace itself; but the pipes are also kept cool by a current of water, which circulates through them and through a water jacket fitted at the back of the rotator for keeping the back plates cool. The elbows or lumps in the lining serve to break up and to turn over the charges as the rotator revolves, thus shortening the duration of the process, and also greatly facilitating the balling up of the charge, and so diminishing the amount of manual labour.

PRODUCTION OF STEEL BY THE CARBURIZATION OF MALLEABLE IRON.

190. Cementation Process.—The cementation or converting process consists in the conversion of bar-iron into steel, by the long continued application of a heat approaching to whiteness, or about 1170°C., to bars of iron embedded in charcoal, the whole contained in suitable chests, and kept out of contact with the air.

The converting furnace has externally the appearance of an ordinary glass-house furnace; it consists of two stone or fire-brick boxes or troughs N, N, called *pots*, each from 3 feet to 4 feet in width, about the same in depth, and 12 feet in length, and open at their upper surface. These pots are arranged one upon each side of the fire-place C, which runs the full length of the furnace, and are contained within the chamber or vault of fire-brick A, covered in by the arch B; beneath and up the sides of the pots are built a number of transverse and vertical partitions respectively, whereby the space along the length of the pots is divided into a number of transverse and vertical flues, so that the gases and products of combustion from the fire circulate under and around the boxes before obtaining access to the flues D,D, and by the short chimneys E,E, with the interior of the dome F, which surmounts and encloses the whole. There are usually three of the short chimneys E along each side of the vault. G is a man-hole in the brick end of the chamber or vault, large enough to admit of the entrance of a man to charge the pots and *draw the heat* after conversion is completed; this hole is placed immediately above the level of the top of the pots, and during the converting process is closely bricked up. Two small holes, called *tap holes*, are left in the ends of the furnace opposite to a corresponding hole in the end of *each pot;* these are for the insertion of *trial or tap bars,*

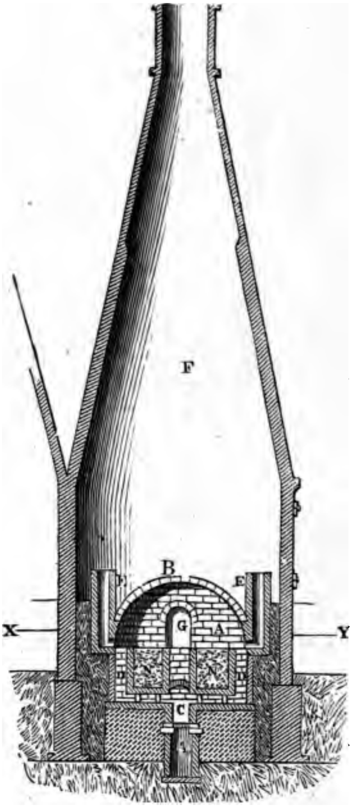


Fig. 50.—Vertical Section of Converting or Cementation Furnace.

that is, bars that are placed so as to allow of their withdrawal from time to time as the conversion proceeds, to examine the progress of carburization in the bars. These furnaces are built in ranges of five or six, or more together.

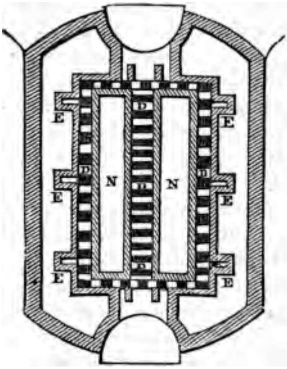


Fig. 51.—Plan of Converting Furnace on Line XY.

The bars for conversion or cementation are from $2\frac{1}{2}$ inches to 3 inches in width, $\frac{5}{8}$ to $\frac{3}{4}$ inch thick, and from 6 feet to 12 feet in length, hammered bars being generally preferred to rolled bars. The pot is charged by placing over the bottom of each a layer of small nubs of charcoal, the charcoal employed consisting of a mixture in about equal proportions of fresh charcoal with that left from a previous charge, after the latter has been freed from the fine dust, etc., which accompanies it on withdrawal from the pots; and charcoal from the harder woods, especially oak, is preferred; on this layer of about $\frac{1}{2}$ inch in thickness is placed a layer of bars, with their flat sides downwards, allowance being made both in length and breadth for their expansion on heating; over the bars again is placed another layer of charcoal, to the same depth as before, then a layer of bars, and so on, alternately charcoal and bars of iron, until the pots are filled, the last layer being charcoal. The surface is then covered over with a thick coating of *wheelswarf*, a mixture of siliceous matter and particles of steel, which collects as a kind of mud in the trough of grindstones, and which, under the heat of the furnace, fuses or frits to a pasty mass of silicate of iron, etc., glazing over the surface and perfectly closing the contents of the pots from the air. The charge for each pot consists of from 12 to 16 tons of bars, though in some cases the furnaces are capable of holding 30 tons of bars. When the furnace is charged, the man-hole is bricked up, the space around the trial bar carefully luted up with clay, and all other apertures made air-tight; after which the fire is lighted, when in about twenty-four hours the pots are at a red heat, and in about two days have attained the temperature necessary for conversion. The heat is now steadily maintained, and for this purpose a coal (as good white ash coal) which does not clinker, but burns uniformly and regularly, is required. The conversion is continued for a period of from seven to nine or ten days, according to the temper the converted bar is required to possess, the harder the temper the longer the process is required to be continued. The trial or tap bar is withdrawn from time to time, and from its appearance on fracture, the progress of the operation is judged. In the early stages of the process, or when the product would correspond to No. 1 temper or "spring heat," the tap bar on breaking shows a thin layer of white steely material, surrounding a nucleus of comparatively unaffected bar-iron or "sap," as it is called; while, as the process advances, the steely character of the surface gradually penetrates through the mass. In No. 4 temper or "double shear heat," the fracture shows about equal proportions of an inner nucleus and of a crystalline steely exterior, though the demarcation between the two should not be sudden; if it be so, it indicates that the conversion is being carried on too rapidly. In No. 6 temper or "melting heat," the inner nucleus or kernel has entirely disappeared, and the conversion is completed; the change having taken place through the entire mass, the fibrous character of the fracture and blue colour due to bar-iron being entirely wanting. When the change is considered complete, according to the purpose for which the steel is required, that is, has attained the required temper, the fire is either drawn, or more usually allowed to burn out, and the furnace allowed to cool down during three or four days; the man-hole door is then taken down, and after an interval of two days longer, a man is able to enter and the withdrawal of the charge commences.

The bars on withdrawal, instead of presenting the smooth surface and tough fibrous fracture with the bluish colour of wrought-iron, present now a surface covered with protuberances or blisters, varying from the size of a pea to an inch in diameter; the bars are readily broken by the blow of a hand hammer, the fracture presenting a crystalline appearance, and the bluish tinge has become sensibly browner or yellower than in bar iron; the specific gravity is also below that of the wrought-iron, and the total product has increased from one-half per cent. to three-fourths per cent. in weight. The bars are now known as "blister steel," or "converted bars." Besides the changes in physical character just indicated, the metal has undergone a marked chemical change; for while the original bar-iron contained not more than ·25 per cent. of carbon, the converted bar will contain from ·5 to 1·5 per cent. of carbon, according to the length of time during which the heat was continued, and the carburization will not be confined to the surface but will extend quite through the mass of the bar.

The origin of the blisters on the surface of the metal has not been clearly accounted for; possibly they may be due to the reduction of the oxide of iron contained in the basic silicate of iron, which is distributed more or less through the bar-iron as mechanically trapped slag, and which by contact with carbon at the temperature required for conversion, suffers reduction, when carbonic oxide would be evolved, which in its efforts to escape while the iron was in a soft condition, might form the blisters on the surface. In the best bars the blisters are tolerably uniform in size, and distributed evenly over the surface, while, if the blisters are irregular in size, and disposed in somewhat definite directions, then there has been a want of homogeneity and regularity in the bars employed. If air has obtained access to the bars during conversion, the bars are rough and have a skin of iron on their surface rendering them difficult to break; *glazed* bars show traces of fusion on their surface, from the temperature of the furnace having been too high. *Aired* and *glazed* bars are unfit for melting into best cast-steel, and require reconverting.

191. Shear Steel.—If the blister steel be cut into suitable lengths, piled together, heated in a hollow coke fire to a welding heat, and forged into a solid bar under the hammer, the bar produced is then known as "single shear steel;" and if this be cut into two parts or doubled upon itself, again welded in the same manner, and drawn into bars, it then forms "*double shear steel.*" To prevent the blister steel suffering oxidation and decarburization while in the fire, the pile or fagot is dusted over with powdered clay, or with sand and borax. The effect of the hammering of the pile or "fagots" has been to render the blister steel (which is never homogeneous) more uniform in composition and texture, and has obliterated all the appearances of lamination which a bar of blister steel exhibits on fracture.

192. **Case-Hardening.**—This is a process by which the surface of articles made of wrought-iron are superficially coated with a skin or layer of steel. The necessary carburization is effected after the article has received its finished form and dimensions, by heating it to bright redness and, if a small article, sprinkling powdered ferrocyanide of potassium over its surface, when the article is returned to the fire for a few minutes and then cooled by immersion in water; for giving a thicker coating, or for case-hardening larger articles, such bodies are placed in wrought-iron boxes, embedded in substances rich in carbon, as fragments of horns, bones, and leather cuttings; the box is then luted up so as to become airtight, and is placed in a furnace where it is maintained at a red heat for about twelve hours, when the fire is allowed to burn out, the box removed, and its contents emptied out.

193. **Cast or Crucible Steel.**—The blister steel prepared by cementation, however much it may be hammered or tilted, unless subsequently fused, is never homogeneous, want of homogeneity arising from the presence of mechanically mixed impurities, as slag, etc., in the original bar-iron, as also from irregularities and fluctuations in the temperature of the different parts of the chest or pot during conversion. Hence, for most purposes, the blister steel is subjected to fusion in crucibles, either alone or in conjunction with bar-iron, carbon, manganese ores, or speigeleisen, when the product is known as *cast-steel*, or homogeneous steel. Cast-steel is also largely prepared by the direct fusion of bar-iron with charcoal and oxide of manganese or speigeleisen, in the manner subsequently described.

The *melting furnace* is the name applied to the part of the building devoted to the melting and casting of the steel. The *furnaces* contain various numbers of "melting holes" or "*fires*," arranged along one or both sides of the furnace, the middle of the floor being occupied by the *teeming holes*, and necessaries for the preparation of the moulds for the reception of the melted metal. The teeming holes are rectangular holes about 3 feet long by 2 feet wide, and of varying depths, in which the ingot moulds are placed so as to allow of the adjustment of their height and inclination for convenience in emptying

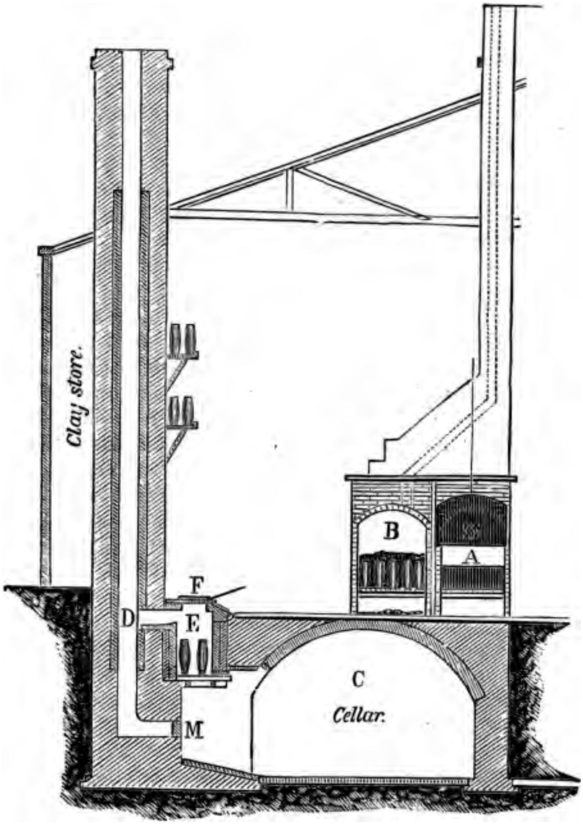


Fig. 52.—Cast-Steel Melting Furnace. A, Annealing Ovens. *B, Annealing* Ovens with front Plate removed.

the contents of the pots or crucibles, technically, *teeming* of the metal; these holes are covered over with iron plates, making them level with the floor of the furnace when the teeming is not going on. The *holes* or *fires* E (fig. 52), are simple rectangular chambers of brickwork, about 3 feet from centre to centre of the partition walls; a wall, single brick in thickness, being the only brickwork separating the fires; but each of these "holes" is lined with a coating some 6 inches in thickness, of a refractory material, as "ganister;" for which purpose oval moulds, patterns, or templates of wood (whose major and minor diameters are 26 inches and 19 inches respectively) are prepared, placed on the fire-bars, when slightly moistened ganister is rammed down around them with an iron rammer; the pattern is then withdrawn, leaving an oval cavity E capable of holding two pots or crucibles. The ends of the fire-bars rest upon bearers built in the brickwork, below the level of the roof of the cellar, and so, in case of running pots, etc., render the bars accessible for withdrawal from the cellar C. The fire is thus allowed to fall through into the ash-pit beneath the bars or grate, so as to permit of the extraction of the faulty crucible. Each fire has its own ash-pit as well as its own flue, D; these flues are carried up in groups of five or six together, to form a stack about 40 feet in height; and each one is carried down below the level of the grate-bars as shown, and opens into the ash-pit, allowing of a communication being opened or closed with it by the insertion or withdrawal of a brick from the opening M; in this manner the draught of the fire can be regulated so as to enable the *melter* to have the contents of all the pots or crucibles melted and ready for casting at the same time. The top of the melting hole formed by an iron plate is level with the furnace floor, and is closed by a cover F, consisting of a square wrought-iron frame, in which is inserted a slab or quarry of fire-brick, about 2½ inches thick; to the frame is attached a round iron bar or rod, inclining slightly upwards, and which forms the handle for the removal of the cover. Each fire holds two pots or crucibles, which are raised about 4 inches from the bars by placing each one on a round stand of fire-brick, and when charged, the pots are covered with flat plates or lids made of a refractory material similar to the crucibles.

The crucibles, which are made of mixtures of fire-clays, with ground pots, and coke dust or plumbago, are from 16 inches to 19 inches in height, 9 inches in diameter at the widest part, and from 5 to 8 inches at the mouth; their preparation has been described on page 22. The pots—hot from the annealing oven shown on page 219, and which is built at the end of the melting furnace—are moved by suitable tongs and placed on their own stands in the fire or melting hole, a small quantity of live coals having been previously placed on the grate; the fire is then made up with coke level with the top of the pots, and the heat raised gradually, when in about half an hour they are ready for charging. From fig. 53 it will be observed that the crucibles, on leaving the mould, have a hole through the bottom, and for the purpose of stopping this (on introducing the metal of the charge) a handful of sand is first thrown in, which at the temperature subsequently attained in the fire, frits and closes the hole, the heat at the same time attaching the crucible and stand together, so that on removing the crucible and melted metal from the fire, the stand is always brought out also. Each pot, if a good one, lasts one day of three rounds or melts, with charges of 50, 44, and 38 lbs. respectively.

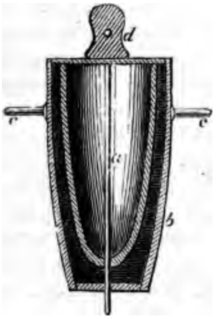


Fig. 53.—Apparatus employed in moulding the Crucibles in which Steel is melted. *a*, plug; *b*, flask; *c*, trunnion arms; *d*, eye-stud at the top of the plug.

If the crucible charge consists of blister steel, the metal is broken up into small pieces by the hammer, and the charge of from 50 lbs. to 60 lbs. of metal, sometimes with the addition of a varying amount of oxide of manganese, is introduced through a wrought-iron funnel-shaped charger into each pot; the lid is placed on the top of the crucible and the fires are then filled up with coke, which burns off in from forty-five to fifty-five minutes; the fire is then pottered down to allow the coke to pass down to the bottom of the pots and again fired; when this second fire has burnt off, the lids of the crucibles are turned off, and the melter goes over the pots inserting a rod of iron into them to ascertain if any portion of the metal is still unmelted, and gives instructions accordingly as to the quantity of coke that is to be added to each fire.

If the molten steel be not allowed to remain long enough in the fire, it will throw out sparks or *teem* fiery, and the ingot will be full of bubbles or holes (honeycombed), when the metal is said not to be *killed;* if it remain too long in the fire it *teems* dead, and the ingot will be of inferior quality.

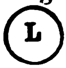
The pots after teeming are conveyed back to the fires, when after the slag and clinker adhering about their bottoms and sides have been broken off by an iron bar, they are at once replaced in the hole; after all the pots have been emptied and thus returned to their places, recharging commences; the *second heat*, as this melt is called, coming down much more quickly than the first; for while the first heat occupied from four and a half to six hours, the second will be melted in about two and a half hours.

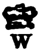
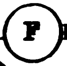
The moulds in which the small ingots of steel are cast are of cast-iron, made in two halves to facilitate the removal of the ingot after casting; the two halves are held together by rings and wedges, and before using each half of the mould is *reeked*, or covered with a layer of coal-tar soot on the inner surface, to prevent the adhesion of the fluid metal to the mould. When soft metal is cast, it rises or boils up after teeming before becoming solid, and a metal stopper is inserted on the top to prevent this action; if the metal be harder in temper, say containing about ·6 per cent. of carbon and upwards, instead of rising, it will *pipe*, that is, the melted metal settles down, leaving a hollow tube in the top of the ingot, which requires to be broken off (that is, the ingot is topped) before working under the hammer. If a large casting has to be made, the pots or crucibles are all first emptied into a ladle with a fire-clay plug in the bottom, by raising which the steel can be tapped from the ladle in a continuous stream into the required mould; or, if the large ladle be not employed, two or more teemers may be engaged at the mould emptying pots, so as to keep up a continuous stream of metal, men bringing up the pots with the assistance of *barrows*, and returning them when empty to the *pullers out*, who reinstate them in the fire. The barrows mentioned consist of a pair of teeming tongs, rather larger than usual, and mounted on a vertical pivot attached to the axle of a pair of wheels, so that a man receives the pot in the bowed jaws of the tongs, then pressing on the handle, the wheels acting as a fulcrum, the pot is raised from the ground, and in this position he then runs it forward to the mould.

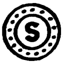
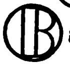
The process just described is that of making cast-steel by melting blister steel or converted bars; but the larger quantity of cast crucible steel is now made from unconverted bars, that is, from the bars of malleable iron direct, without the intervention of the process of *converting* or *cementation.* For this purpose the bars are cut by shears into pieces about ¾ of an inch square, and charged into the pots in the manner last described, except that there is also added at the same time a quantity of charcoal varying in amount from half an ounce to eight ounces per charge, according to the *temper* of the steel to be produced; and after the second fire has burnt off, a quantity of *speigeleisen* (the highly carburized and manganiferous pig-iron already described) is usually added, the operation in other respects being the same as that described in the last article. For the preparation of the softer or mildest tempers of steel, instead of adding the charcoal above mentioned, the melting is performed in *black* or *plumbago* pots, that is, in crucibles containing a large amount of plumbago, with only sufficient fire-clay to give the necessary plasticity to the mixture. Steel melted in such pots obtains an amount of carbon from the material of the pots sufficient to convert the bar-iron into steel, with the addition only of from 1½ per cent. to 4 per cent. of speigeleisen; in other respects the operation is conducted as before. For steel that requires to be of a hard temper, but yet capable of welding easily to either itself or to iron, as for certain classes of cutlery, etc., the larger proportions of charcoal are added, with a few ounces of oxide of manganese, while the addition of speigeleisen is not then made. Charcoal prepared from the oak is preferable to that from the softer woods.

For the manufacture of best crucible steel, Swedish bar-irons made from *magnetic iron ores,* practically free from sulphur and phosphorus, and smelted with charcoal, are preferred;

the irons made from the ores in the district of Dannemora, in Sweden, being especially prized, and command accordingly high prices in the market; ranking next are probably the Persberg irons, also Swedish. Each bar of Swedish iron is stamped with a letter or mark, ceded by the Swedish Government (and registered by the Board of Trade) to the owners of the works where the iron is made; the number of these brands is accordingly almost legion, and it will suffice here to note a few of the more important Dannemora brands. Amongst the *best* marks are :—

 hoop L, and OO double bullet.

 W and Crown  Hoop F, *Middle Dannemora Marks.*

 little S.  gridiron, *Common Dannemora Marks.*

Numerous chemical *physics* have been, and are still used in Sheffield for the improvement of cast-steel, or the manufacture of best-steel from inferior brands of iron; of such may be mentioned sal-ammoniac (NH_4Cl), common salt ($NaCl$), common rock salt, nitrate of potash, chromate of potash, prussiate of potash, iodide of potassium, fluorides (will be noticed as the "Henderson" process), manganese now universally used, and numerous alloys of the rarer metals, of which something is said under the head of "Alloys of Iron and Steel."

The addition of iodide of potassium to the crucible charge constitutes the *Sherman process*, and has for its object the removal of the sulphur and phosphorus from the iron, in virtue of the powerful affinity existing between these elements and iodine; chemical analyses and mechanical tests applied by the writer have failed, however, to show any decided advantage from its use.

194. Melting in Reverberatory Furnaces.—The decarburization of the steel and the corrosion of the furnace by the oxide of iron formed, have prevented the adoption of the ordinary reverberatory furnace for the melting of cast-steel; but in France, a series of chambers each holding several pots, and heated by the flame from the combustion of fuel on a separate fireplace, have been used, the combustion being urged by a chimney aided by a blast introduced beneath the grate. To overcome the difficulty of oxidation, etc., it has been proposed to effect the fusion under a slag of bottle glass, but with the use of solid fuels this process has never been successful. The furnace employed in the Siemens-Martin process is essentially a reverberatory furnace, with the application of gaseous fuel from the Siemens generator.

195. Siemens' Melting Furnace.—The Siemens regenerative gas furnace has been applied to the melting of cast-steel in crucibles, and is reported to effect a considerable saving in the item of fuel, three tons of coal slack distilled in his generators, and the gas therefrom subsequently consumed in conjunction with his regenerators, melting an amount of steel which, in the ordinary manner, required about seven tons of coke for its melting. The gas producer and the regenerators have been already described (pp. 62 and 174), and it is only necessary to add here, that to apply them to steel melting, the pots are placed in a chamber above the level of, and between the two series of regenerators, leaving an arched vault beneath the furnace bottom. The melting chambers are formed of brickwork arched horizontally and vertically, and strengthened by cross walls at intervals, and of sufficient length to contain 24 pots or crucibles arranged in pairs; they are 3 feet 6 inches wide at the bottom, and 2 feet wide at the opening along the top, which is closed or covered by loose fire-brick covers. The heated gases and air rise through the heated regenerators at one side of the chamber, and are drawn down through the regenerators at the opposite side by the draught produced by the stack with which they are connected; and by placing the pots on suitable platforms connected with mechanism in the vault or cave beneath the melting chamber, they can be raised in groups from the furnace without the labour of removing the pots singly, thereby facilitating the casting of large ingots or masses of steel.

196. Wootz.—The Hindoo steel which has received this name, is obtained by treating malleable iron in small unbaked crucibles, with 10 per cent. of its weight of the leaves and stems of the *cassia auriculata*, the charge of metal for each pot being a little over 1 lb. in weight. The surface of the charge in the pot is covered by two smooth green leaves of the *asclepis gigantea;* the lid is then carefully luted on, and about twenty of the pots are then arranged so as to form an arch or dome over a small cavity made in the ground, one pot being removed for the insertion of the nozzle of a pair of very primitive bellows, and for the introduction of the charcoal fuel into the pit or recess. The heat is maintained for a period of from two to four hours, when on breaking the pots, a small cake of hard steel, presenting a series of striations on its surface, is obtained from each pot. Wootz is stated to be a superior class of steel, but requiring great care in its working. In some specimens *aluminum* has been detected, but it is not considered to be an essential element of the Hindoo metal.

DECARBURIZATION METHODS FOR THE PRODUCTION OF STEEL.

197. Puddled Steel. — The conduct of this process is essentially the same as the ordinary puddling process for the conversion of pig into malleable iron, except that the *fining* is carried on more slowly, so that although the decarburization is not so complete as in ordinary puddling, still the process usually occupies a few minutes longer for its completion. The slag in this process is required to be more fluid and less decarburizing than when malleable iron is to be produced, and hence the use of a pig-iron containing a large proportion of manganese, such as *speigeleisen,* is desirable for this process, the manganese forming a more fluid and less highly basic slag than when ferrous oxide with only a small quantity of manganous oxide forms the basis of the slag.

The operation is conducted in a puddling furnace differing but slightly from the furnace employed for the production of malleable iron, the chief differences being, that the bed is smaller, the area of flue to grate is greater, as also the height of the bridge is some few inches greater than in the ordinary puddling furnace, whereby the grate contains an increased depth of fuel, and so enables the workman to maintain a more powerfully reducing flame when such is required.

The charge of pig-iron is reduced into small pieces as uniform as possible in size, and from 3 to 4 cwt. is spread evenly over the bed of the furnace, a pretty strong heat being maintained so that it may melt rapidly without unnecessary oxidation; in this stage the temperature is higher than when wrought-iron is produced, and the charge is melted in from forty to fifty minutes; the damper is now closed until the metal thickens and begins to rise, when the mass is rabbled or stirred continuously, the damper being carefully raised so as to maintain the charge thoroughly melted, the continued stirring keeping the mass uniformly carburized by the continual passage of the decarburized metal from the surface into the bath of metal below. In from thirty-five to forty minutes from the commencement of stirring, floating granules of metal begin to appear, and from the appearance of these grains is afforded an indication of the quality of steel that is being produced; if the grains are white and brilliant, the metal will probably be uniform and of good quality, but if large and flaky, the steel has a tendency to be coarse and inferior in quality. At this stage the *balling* commences; the damper is again partially closed, whereby the temperature is reduced and the bed or hearth of the furnace is filled with flame of a non-oxidizing character, which is essential in this part of the operation, otherwise either iron or steel with an insufficiency of carbon results. The balling operation requires considerable care and practical skill for its successful performance, and is effected at a lower temperature than when balling wrought-iron; the balls also require hammering or shingling with greater care, and at a lower temperature than malleable iron, especially so if a hard or highly carburized steel has been produced. During the *boiling* and *fining* stages of the operation, the mass presents the same appearance of jets of burning carbonic oxide which appears in the ordinary puddling process; the difference between the two processes consisting in stopping the puddling at a point before complete decarburization is effected, if steel is the product required.

Mixtures of pig-irons are to be avoided in this process, since one kind of pig-iron might probably *fine* and *come to nature*, while the other remained quite fluid and highly carburized, notwithstanding the presistent stirring.

The process as at first introduced into England by Mr. E. Rieppe and practised at the Mersey Steel and Iron Works, was conducted slightly different from the method above described; the charges were smaller, and when the metal began to fuse, forge or mill cinder was added, after which when the charge was fully melted, a small quantity of a mixture of black oxide of manganese, clay, and common salt was added; the temperature was then raised, and 40 lbs. of pig-iron was placed on beds of cinder near the fire-bridge, which, on beginning to melt, was raked down into the melted bath below, and thoroughly mixed with it. Grains of steel then began to appear, when the temperature was reduced while the bath was rabbled beneath the layer of cinder, after which the balling was effected as before with the damper closed.

The Siemens' furnace has been applied to this process, effecting thereby a considerable saving in fuel. Puddled steel, however, is never uniform, and from the intermixture of cinder, etc., requires re-melting before it can be applied to many purposes; and it also welds imperfectly.

The following analyses of the pig-iron employed, and the steel produced in this process, are by Schilling.*

	Puddled Steel.	Pig-Iron.
Graphite, - - - - - - -	...	·08
Combined Carbon, - - - - -	·94 per cent.	2·60
Sulphur, - - - - - - -	Trace.	·09
Phosphorus, - - - - - -	·075 ,, ,,	·48
Silicon, - - - - - - -	·11 ,, ,,	·99
Manganese, - - - - - -	·27 ,, ,,	2·01

It will be observed from these analyses that the change in composition from pig-iron to puddled steel, is exactly analagous to that which takes place in puddling for malleable iron, viz., a very considerable decrease occurs in the percentage of the whole of the elements—carbon, sulphur, phosphorus, silicon, and manganese—a result which, in regard to sulphur and phosphorus, contrasts strongly with the result when the same pig is treated in the Bessemer process, where these elements remain in the final product undiminished, or even concentrated. For the more perfect elimination of the deleterious elements, sulphur and phosphorus, during the puddling and other steel-making processes, various *physics* have been proposed for addition to the charge at different stages; of such are "Schafhäutl's powder," consisting of oxide of manganese and common salt, with a little potter's clay; while other mixtures contain carbon, chromate of potash, ferrocyanide of potassium, cyanogen compounds, etc.

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* Bauerman, *Metallurgy of Iron.*

In Westphalia,* puddled steel is rolled into pieces of $\frac{1}{2}$ or $\frac{3}{4}$ of an inch square, and sold in Hamburg under the name of *India steel;* the same steel when hardened, is sold as *Mailand steel.*

198. Heaton Process.—In the Heaton or *nitrate* process for the production of steel, the pig-iron is first converted by treatment with nitrate of soda into what he calls "crude steel," which product requires to be broken up and melted in crucibles for the production of cast-steel. The converter employed, fig. 54, consists of a cylindrical wrought-iron cupola, surmounted by a cone, and terminating in a short vertical chimney; the whole is lined with refractory material, as fire-brick or fire-clay. The bottom, which is raised above the level of the floor to allow of the introduction of a waggon or truck beneath it, is made movable and secured to the cupola by iron clamps. In conducting the process, nitrate of soda, forming about 10 per cent. of the charge, sometimes mixed with sand and air-slaked lime, is first placed on the bottom C of the cupola, and prevented from at once floating up through the liquid metal by a closely-fitting cast-iron grate or perforated plate B, which is placed upon it; the molten pig-iron is then introduced through the opening A, when in about two minutes† brown nitrous fumes appear, succeeded by blackish, grey, and then whitish fumes, and in about five or

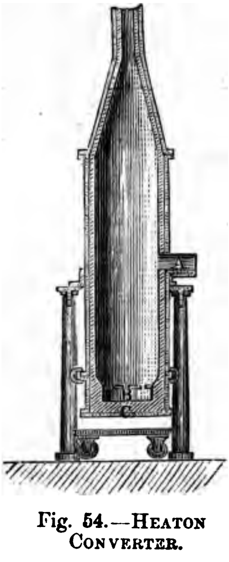

Fig. 54.—HEATON CONVERTER.

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* Crookes' and Rohrig's *Metallurgy.*

† Professor W. A. Miller's Report on the process.

six minutes the plate separating the iron from the nitrate of soda is melted, and a violent decomposition ensues accompanied by an active ebullition and the emission of a bright yellow flame from the top of the chimney; this continues for about a minute and a half, when the action ceases, and the metal quietly subsides. The charge is not usually sufficiently fluid to be run out into moulds, so the bottom of the converter is detached and received into a truck beneath, when the product or *crude steel*, along with the slag, is poured on to the iron floor; the metal is then broken into pieces of convenient sizes for piling and reheating, when, after shingling, the blooms are cut up, reheated, and rolled into bars, or, if required for the production of cast-steel, the blooms are hammered into flat cakes which are broken up, sorted, and remelted in crucibles.

Analyses of the pig-iron employed and the crude steel as received from the converter, show that the oxidation from the decomposition of the nitrate has had the effect of removing all but a trace of the silicon, while the carbon is partially removed, and what remains is wholly in the combined state. The following analyses, published by the late Dr. W. A. Miller, F.R.S., and Mr. Snelus, respectively, show that the phosphorus and sulphur are but imperfectly removed.

ANALYSIS OF HEATON PRODUCTS (DR. W. A. MILLER, F.R.S.).

	Pig-iron employed.	Crude Steel.
Carbon	2·830	1·800
Silicon	2·950	0·266
Sulphur	0·113	0·018
Phosphorus	1·455	0·298
Arsenic	0·041	0·039
Manganese	0·318	0·090
Calcium	...	0·319
Sodium	...	0·144
Iron (difference)	92·293	97·026
	100·000	100·000

ANALYSIS OF HEATON PRODUCTS (SNELUS).

	Two brands of Pig-iron mixed together.		Soft Crude Steel.	Hard Crude Steel.
Graphite - - - - -	2·360	2·570	1·098	2·061
Combined Carbon - -	0·446			
Silicon - - - - -	2·006	1·959	Trace.	0·014
Sulphur - - - - -	0·034	Trace.	Trace.	Trace.
Phosphorus - - - -	0·446	0·558	0·344	0·489
Manganese - - - -	0·648	0·885	0·072	0·064

199. Uchatius' Process.—This process, patented in 1855, depends for its success upon the decarburization of pig-iron by heating it with roasted ores of iron. For this purpose the pig-iron is melted in a cupola, and granulated by running the melted metal into cold water, by projecting it in globules, by allowing the melted metal to fall upon a horizontal revolving disc or dash wheel, or any other method by which the pig-iron can be obtained in small particles. The granulated iron is heated in crucibles along with 20 per cent. of its weight of roasted pulverized oxide of iron or spathic iron ore, a little black oxide of manganese, and about 4 per cent. of fire-clay, this latter serving to form a slag with the extraneous matters of the ore. The spathic ore (carbonate of iron and manganese) is oxidized during roasting to ferric oxide, etc., which, in the crucible, is reduced by the carbon of the pig-iron whereby carbonic oxide is evolved and the charge of pig-iron in the crucible is decarburized. The product of cast-steel exceeds by about 6 per cent. the weight of the pig-iron employed.

The finer the granulation of the pig-iron, the softer or milder is the temper of the steel produced; the temper is also regulated by the addition of small pieces of malleable iron if the temper is required to be lowered, or of charcoal if the metal is to be hardened. In Sweden this process is carried on successfully by melting pig-iron with certain Bispberg magnetic iron ores. In England, however, the uncertainty in the quality of the cast-steel produced has prevented its extensive introduction.

200. Ellerhausen's Process.—This process is similar to the last, but differs in the manipulation. The pig-iron is run directly from the blast furnace along a spout into moulds formed on the circumference of a revolving table; at the same time, another spout delivers into these moulds finely divided *hæmatite, iron sand* or powdered *magnetite,* the result being, that by revolving the table as each mould is filled, a series of pigs or blooms of pig-iron mixed with about 15 per cent. of iron ore is obtained. These *pig-blooms* are melted and puddled in the puddling furnace; and it is stated that the metal in this condition is more easily puddled than ordinary pigs, giving also an increased yield of metal. The process can be applied either to the production of malleable iron or steel, according to the degree of decarburization effected in the puddling process; but the method is not received with favour in England.

Numerous other patents exist for the fusing of mixtures of pig-iron with special ores of iron, with substances as arsenious acid, nitre, etc.; but the difficulty encountered in the whole of these processes appears to be the uncertainty of the quality and temper of the product.

201. Henderson Process.—This process, known also as the *fluorine process,* has for its object the removal of sulphur, phosphorus, and silicon from pig-iron, by the action of fluorides upon the metal during its conversion into steel or malleable iron. In one modification of the process, a titaniferous pig-iron is first produced by fusing pig-iron such as that of the Cleveland district with titaniferous iron ore, and then charging this titaniferous pig upon the bed of a puddling furnace, the bottom of which has been covered with fluor spar (fluoride of calcium). The metal requires no rabbling, except for balling up the finished product.

In the second modification a mixture of 48 lbs. of fluor spar with 118 lbs. of titaniferous iron ore, both ground fine, is spread evenly over the bottom of the puddling furnace, and the charge of 475 lbs. of pig-iron placed thereon. The furnace, thus charged, is closed so as to prevent the access of air, and the temperature is raised as high as possible; after a lapse of seventy minutes samples are taken from the bath every few minutes to ascertain the progress of the conversion, and in about an hour and a half the operation is completed. The metal should not be stirred or rabbled during the conversion, since the mixture of fluor spar and titaniferous iron ore is only rendered viscous, and not perfectly fluid, by the heat attained in the furnace; and if stirring be not resorted to, it will remain on the bottom of the furnace, where the fluor spar will be decomposed by the reaction upon it of the silicon and other elements of the pig-iron.

202. **Parry's Process.**—Mr. Parry states that the ordinary puddling process effects the removal of about 75 per cent. of the phosphorus, and from 65 to 70 per cent. of the sulphur present in the original pig-iron; hence by repeating the puddling operation upon the malleable iron first produced, further reductions in like proportions will be made in the residue of sulphur and phosphorus remaining in the malleable iron, and the *twice puddled products* will therefore be practically free from these noxious elements. If necessary, the conversion into pig-iron and *re-puddling* may be repeated a third time, each conversion being attended with a diminution in the amount of the sulphur and phosphorus present in the product. Mr. Parry therefore proposed—1, to reconvert wrought-iron scrap (that is, pig-iron that has been subjected to the puddling operation) into pig-iron, without the introduction of any further amount of sulphur or of phosphorus; and 2, to re-puddle this product. The reconversion into pig-iron is effected in a cupola or blast furnace, the increased temperature necessary for the recarburization being attained by inclining one or more of the twyers, at an angle of 30° or 35° downwards. The cupola charges consist of about 7 cwt. of coke per ton of iron, with sufficient lime to flux the ash of the coke. The furnace must be kept filled during the melting, otherwise an insufficient amount of carbon will be taken up, about 2 per cent. being necessary to produce the boil in the puddling furnace, and to this extent the wrought-iron must be carburized. The metal from the furnace is tapped in the usual manner into pigs, which are puddled in an ordinary furnace and rolled into merchant bars in the usual manner. The product is called *purified wrought-iron.*

For making hard steel, Mr. Parry repeats the carburization just described, except that the amount of coke used is reduced from 7 cwt. to 4 or 4½ cwt. per ton of metal, and the size of the nozzles of the twyers is slightly increased. For the production of soft or mild steel, the metal so obtained is run out into an oval-shaped vessel or receiver of wrought-iron, lined with a mixture of clay and sand, and connected with a blowing apparatus for passing air through the mass; after a few minutes' exposure to the blast, the temper of the metal is sufficiently reduced, and it is run out from the tap-hole in the bottom of the vessel into ingots or other forms.

203. Malleable Cast-iron.—The operation of converting the surface of articles of cast-iron into malleable iron or soft steel, is a process analagous to the cementation of steel, except that instead of carbon, the cement powder consists of powdered peroxides of iron, a decarburizing material. The object of the process is to partially remove the carbon, sulphur, silicon, and manganese from the surface of articles made of cast-iron, and so impart to them the strength and softness of malleable iron or mild steel; for this purpose the articles are cast in moulds in the usual manner, the iron preferred for the purpose being charcoal pig smelted from red hæmatites, and the castings so produced are then packed into suitable boxes or crucibles, with powdered red hæmatite. A number of these crucibles are arranged in a rectangular furnace chamber, and the heat gradually raised, when in about twenty-four hours the whole contents of the furnace are at a red heat; the heat is then continued for from three to seven days, according to the size of articles, and the extent or depth to which it is desired that the decarburization shall penetrate.

Malleable cast-iron cannot be welded or worked when heated, since there remains an inner nucleus or kernel of cast-iron, which, melting below the welding heat of steel, causes the object to fall to pieces at the stroke of the hammer; the surfaces may, however, be readily brazed together and, in the cold state, the castings may be hammered to a certain extent, or can be filed or fitted as articles of malleable iron.

PRODUCTION OF OPEN-HEARTH STEEL BY THE FUSION OF PIG-IRON WITH MALLEABLE IRON OR STEEL SCRAP; OR OF PIG-IRON WITH IRON-ORES.

The open-hearth steel processes embrace, firstly, the *Siemens-Martin process*, as pursued most largely on the Continent, and by which steel is produced by the fusion of pig-iron with steel scrap upon the hearth of the Siemens' regenerative gas furnace. Secondly, the *Siemens' direct open-hearth* or *ore process* in which pig-iron is decarburized and steel produced, by the addition of certain pure iron-ores to the bath of molten pig-iron on the furnace hearth; and lastly, the combination of the two above-mentioned processes, in which *pig-iron, scrap steel*, and *iron-ores*, are all added to the furnace in the manner subsequently to be described.

204. The Siemens' Open-Hearth Steel-Melting Furnace.—This furnace is employed in the production of open-hearth steel, by whichever of the above modifications it is produced. The furnace, figs. 55, 56, has a bed B which slopes from all sides towards the tap-hole K. The bed is supported upon cast-iron bed-plates and bearers which are kept cool by the free circulation of air beneath them. The regenerators, A, A, G, G, for heating the air and gas respectively, are placed transversely beneath the bed of the furnace. The roof *d* of the furnace usually dips from either end towards the centre, so as to deflect the flame more strongly down upon the bath of molten metal on the hearth; but this construction of roof is not always observed, and an ordinary flat arched roof may be adopted. The two ends of the hearth are built quite symmetrically with respect to the hearth, and are, like the reheating (p. 199) and puddling furnaces (p. 174), provided at each end with openings or ports, *b*, *b*, communicating by suitable passages with the regenerators G, G, and through these the gas is admitted to the furnace; whilst above and generally behind these are three other ports, for the admission of the heated air from the regenerators A, A. In the front or working side there are three doors *n*, of which the two outer or end ones, are used for the introduction of the charge of pig-iron and of scrap, whilst the central one, placed a little lower than the

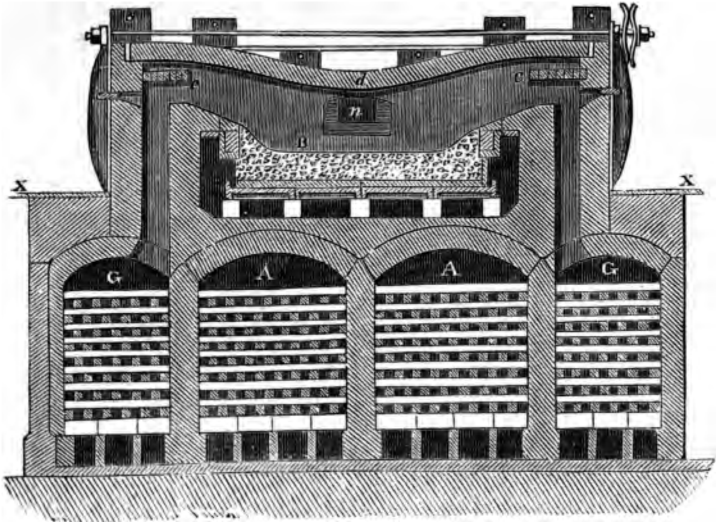

Fig. 55.—*Longitudinal Section.*

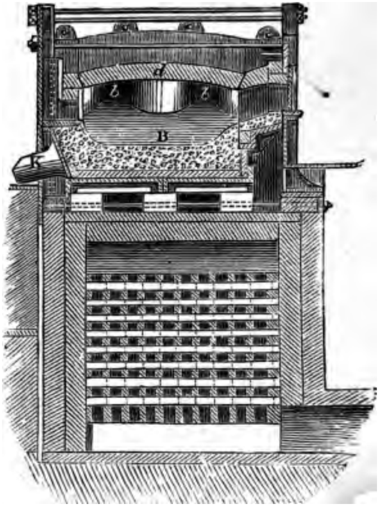

Fig. 56.—*Cross Section.*

SIEMENS' OPEN HEARTH STEEL MELTING FURNACE.

other two, serves as the working door of the furnace, for the rabbling, etc., of the charge, and the introduction of iron-ore, limestone, flux, etc., when such are required. The plates at the back, or tapping side of the furnace, are usually provided with three openings, but these are ordinarily bricked up, and only used as may be required for the repair of the bottom, etc. The furnace is supported externally by plates, buck-staves, and tie-rods, after the usual manner of reverberatory furnace construction. The roof and ports of the furnace are built of the most refractory silica or Dinas' bricks; and since such bricks expand very considerably on heating, it is necessary to supply springs or nuts to the ends of the tie-rods which pass over the roof of the furnace, the nuts being screwed back as the furnace is first heated up, so as to allow of the expansion of the bricks without materially altering the form of the roof, otherwise the roof rises and becomes distorted by the expansion. The bottom or bath plates of the furnace hearth, are lined with a single course of fire bricks, upon which, when the furnace has been heated up, the working bottom, B, of a fine quartzose sand, is made by introducing successive layers of sand of about one inch in thickness, and allowing each layer to slightly vitrify or glaze on the surface, before another layer is added. These furnaces are supplied with gas from the Siemens, the Wilson, or other gas-producer, and the supply is regulated by mushroom valves fitted to each furnace, whilst the arrangement of flap valves, already described (p. 175), is applied to the gas and air culverts for reversing the direction of the current of gases and air from one end of the furnace to the other, as required for heating up the regenerators, and so maintaining a high initial temperature of the gas and air as they enter the furnace. Each furnace, or every pair of furnaces, is usually supplied with its own stack for promoting the necessary draught required to draw the waste gases downwards, from the hearth and through the regenerators.

These furnaces are built of sizes which are capable of melting from 6 tons to 15 or 20 tons of steel at a single charge.

The molten steel is received from the tap-hole, K, into a suitable ladle, similar to the Bessemer ladle described (p. 249), and the casting arrangements are similar to those described for the Bessemer process, but special devices are also adopted for emptying the ladle into the moulds, according to the size of the ingots to be produced and other local requirements.

205. Siemens-Martin Steel Process.—By this process, open-hearth, or Siemens-Martin steel, is produced by the melting of wrought-iron, or steel scrap of various kinds in a bath of molten pig-iron. The fusion is most generally effected in the Siemens' regenerative furnace last described, but the Pernot revolving, and other similar furnaces, are also occasionally employed for this purpose.

The furnace having just tapped out its charge of steel, the sand bottom always requires more or less repairs, for which purpose dry sand is introduced as required to level up any hollows that may have been formed, after which the charge of cold pig-iron and scrap is introduced. The pig is first distributed over the bottom of the furnace, and the scrap is then placed upon it, the larger pieces of scrap being generally placed on the bank or higher part of the hearth, near to the ports of the furnace at the two ends, so that in this manner the scrap becomes thoroughly heated before it is rolled down into the bath of fluid pig-iron, which first collects on the hearth.

The proportion of pig-iron to scrap in the charge, varies with the supplies of scrap which are available, but generally from 15 per cent. to 20 per cent. of the charge consists of grey Bessemer pig-iron, although white or mottled hæmatite iron is also frequently used in this process; the remainder of the charge consists usually of various Bessemer or Siemens steel scrap, borings, shearings, crop ends of rails and bars, etc. A charge of 7 or 8 tons, made up in this manner, is all melted down in about four hours, during which period an oxidizing flame is maintained in the furnace, and the gas and air valves are each reversed at regular intervals of about thirty minutes. Sampling of the metal and examination of the slag, is then made at intervals, for which purpose specimens of the metal are withdrawn from the furnace, by means of a small iron ladle or spoon, the samples are cooled in water, then hammered and broken, so as to judge of the malleability and fracture of the metal. Towards the end of the process (as the toughness and malleability of the specimens increase, indicating an approach to the desired degree of decarburization), chemical analyses are also rapidly made for the determination of the carbon in the metal by the colour test. When the desired decarburization has been attained, about 1 per cent. of speigeleisen, containing from 10 to 20 per cent. of manganese, along with a like amount of ferromanganese containing from 60 to 80 per cent. of manganese, is added to the bath; but the total amounts, as also the proportions of these recarburizing and manganiferous additions, depends upon the temper of the metal to be produced. The speigeleisen and ferromanganese melt in a few minutes, during which period the bath is stirred or rabbled, in order to effect a thorough mixture of the recarburizing materials with the bath of metal; and after standing for a few minutes further, for the better separation of the slag, etc., the metal is tapped out from the furnace.

In order to tap the furnace, the sand near the tap-hole is first drawn out with a bar, and finally a pointed bar is driven through the hard crust which forms on the inner surface of the furnace bottom, and on withdrawing this bar the molten metal follows, and is received in a heated ladle, previously prepared and which is standing beneath the spout for its reception. The ladle is then passed in succession over the several ingot moulds, arranged either in a circular or a straight pit, and the metal is tapped from the ladle, through the nozzle in its bottom, into the several moulds in succession. The ingots are then *stoppered* by throwing sand on the surface of the metal, placing iron plates upon this, and wedging down the same with suitable wedges; or, instead of this, loosely fitting iron stoppers are inserted into the several moulds, and sand is thrown upon the top of the same.

A charge of 8 tons is usually worked off by this process in about seven hours, while another hour is occupied in tapping, repairing the furnace, and the preparations for re-charging; but the total number of charges worked off per week from each furnace varies with the temper of the metal and with the condition of the furnace.

The yield of steel is from 5 to 8 per cent. less than the combined weights of pig-iron and scrap charged into the furnace.

It was a former practice to supply pockets, or auxiliary heating apparatus, for heating the scrap before introducing it on to the hearth of the melting furnace, but this procedure is not now generally pursued, the whole charge being introduced into the furnace in the cold state.

206. Siemens' Open-hearth Steel Process.—Like the Siemens-Martin or scrap process, the Siemens' open-hearth steel process is conducted in the open-hearth regenerative gas furnace (p. 236); but, unlike the Siemens-Martin process, it employs rich Algerian or Spanish hæmatite iron ores, as a principal decarburizing agent. In the Siemens process the charge, consisting either of pig-iron alone, or, as is usually more convenient, of hæmatite *pig-iron* and *steel-scrap*, in the proportion of about 30 per cent. of the former to 70 per cent. of the latter, is charged and melted upon the hearth of the furnace, after which from 15 per cent. to 20 per cent. of Elba, Mockta, Sommorostra, Marabella, or other pure red hæmatite iron ore, in lumps, is gradually added to the molten charge. A little limestone is also added, as may be required, to produce sufficient slag to cover the surface of the bath of molten metal, and also to prevent the loss, as far as possible, of the iron which would otherwise escape as ferrous silicate into the slag.

The conduct of the Siemens process is similar to that already described for the Siemens-Martin process, that is, the furnace being hot and the bottom having been repaired, the charge of pig-iron is first introduced and distributed over the hearth, while the scrap-steel is placed upon the pig-iron. The charge is then melted down, the oxidation of the impurities proceeding as described in the last process; but the decarburization is further promoted, after the completion of the melting-down stage, by throwing into the bath of molten metal such iron ores as those above mentioned, which ores should be as free as possible from phosphorus, or sulphur and sulphates. Each addition of ore at once throws the bath into a state of violent ebullition, due partly to the escape of moisture from the ore, but more largely from the evolution of carbonic oxide, as the result of the oxidation of the carbon in the pig-iron, and the reduction of iron from the ore. Samples of the metal are withdrawn at frequent intervals and tested for malleability, toughness, and for carbon, exactly after the manner described in the Siemens-Martin process, and either more ore, pig-iron, or scrap is added to the bath, according as the decarburization is incomplete or has been carried too far.

When the charge has reached the required degree of decarburization, the metal is allowed to stand for a few minutes tranquil in the furnace for the separation of slag. The speigeleisen or ferromanganese, or a mixture of the two, is then added as required, to produce the necessary recarburization of the metal. But for the production of very soft qualities of Siemens steel, no manganiferous alloy or speigeleisen is added to the furnace, the recarburization being effected entirely by the addition of from $\frac{3}{4}$ cwt. to $1\frac{1}{4}$ cwt. of red-hot ferromanganese to the ladle as the metal runs into the same from the furnace. The tapping and casting arrangements do not differ from those already described for the Siemens furnace.

The duration of the Siemens process is usually from nine to eleven hours, or is a little longer than the scrap process for the same weight of charge, whilst the corrosion of the sides of the hearth and of the ports, is greater in this than with the Siemens-Martin process. The yield also of this, which is frequently also spoken of as the ore process, usually exceeds by 1 per cent. or 2 per cent. the total amount of pig-iron and scrap charged into the furnace, owing to the reduction and addition thereby to the charge, of about one-half of the iron contained in the ores which are used in the decarburization of the pig-iron. The consumption of fuel in the gas-producers amounts to from 11 cwt. to 14 cwt. of small coal to the ton of steel produced.

207. Reactions in the Open-Hearth Steel Process.—The open-hearth steel process, like the Bessemer process, proceeds first to almost totally decarburize the metal of the charge, and then to recarburize the same to the degree corresponding to the required temper, by the addition of speigeleisen or of ferromanganese. These substances introduce into the steel, however, besides carbon, iron, and manganese, also small proportions of sulphur, silicon, phosphorus, and copper, which are always present in these highly maganiferous bodies, but the use of ferromanganese instead of speigeleisen reduces to a minimum the proportion of the last-mentioned elements so introduced, owing to the smaller weight of ferromanganese which it is necessary to use.

In the first or melting down stage of the open-hearth processes, silicon, manganese, and carbon are all more or less oxidized, so that at the end of this period about one-half of the proportion of these elements originally present in the charge has been removed—the two first mentioned in the slags. In the second stage, which lasts from three to four hours, the molten metal lies tranquil on the hearth, and during this period the silicon and manganese are being principally oxidized, for the carbon is not materially reduced until the proportion of silicon in the metal has been reduced to about 0·02 percent. The third stage or boil ensues, and it is attended by an appearance of ebulition, resulting as previously stated, from the escape of carbonic oxide, which burns in blue jets over the surface of the metal. The boil continues until the carbon has fallen to about 0·1 per cent. when the bath again becomes tranquil. The slag also, which has hitherto been of a brown colour, begins towards the end of the process to blacken, owing to the oxidation and waste of a little iron, which thus escapes as ferrous silicate into the slag.

In the ordinary or silica-lined furnace, there is little if any separation of either sulphur or phosphorus during the production of the steel, and hence, as before mentioned, only such pig-irons as are low in these elements are available; but in a furnace lined with basic materials such as bauxite, magnesite, or calcined dolomite and coal tar, coupled with a tolerably free addition of lime to the charge, then the sulphur and phosphorus can be removed and it becomes possible to employ inferior pig-irons. Large proportions of manganese in the pig-iron also prolong the duration of the decarburization stage of the process, besides rendering the charge more corrosive in its action upon the lining of the furnace. Pig-iron, which is low in carbon and silicon, is preferred for the open-hearth processes, since then the time required for fining is shortened, and also a superior metal is generally produced, but in all cases a mixture of several brands of iron is advantageous for the production of a uniform quality of metal.

208. Use of Blast in the Open-Hearth Processes.—It has been proposed to use a blast of air or steam, for the more rapid oxidation of the silicon and manganese during the earlier stages of the open hearth process, which immediately follow the melting down of the charge, whilst completing the last stages of the decarburization in the regular manner without any blast. In some of the continental works this is effected by structural alterations of the furnace, or in others, more simply by the use of a hollow rabble with the ordinary Siemens open-hearth melting furnace. The latter method, as carried on at Ruhrort, consists simply of an iron pipe and nozzles coated with clay, one end of the pipe being coupled by india-rubber connections with a pipe from the blowing apparatus, whilst the other end of the rabble (which is introduced through the furnace door) is connected with three nozzles or twyers of about 1 inch in diameter, and each of which delivers three jets of air into the bath of metal. The twyers are bent downwards from the pipe, so that when the apparatus has been introduced into the furnace, the blast is turned on, and the pipe or rabble is then twisted so as to insert the twyers below the surface of the metal, whereupon an action similar to that of the Bessemer process ensues, which is attended in like manner with a considerable rise in the temperature of the metal upon the hearth. In this manner the silicon and manganese are largely and quickly removed, after which the blast apparatus is withdrawn, and the completion of the decarburization is then effected after the usual manner. This combined open-hearth and Bessemer process, while shortening the total duration of the process, allows of the same desirable examination of the final product, as is possible with the normally conducted open-hearth processes. Practical difficulties in the conduct of the compound *Bessemer and Siemens* process have, however, prevented any general introduction of it.

209. Pernot Revolving Furnace.—For the conduct of the open-hearth steel processes, revolving furnaces such as the Pernot and the Ponsard furnace (p. 199), are in use in some of the continental works, but the writer is not aware of any English works where these furnaces are now in successful operation.

The Pernot furnace has a revolving hearth of from 7 feet to 14 feet in diameter, and about 8 inches or 9 inches in depth. The hearth is mounted on wheels and is inclined at an angle of about 6° to the horizontal, so that as the molten charge lies on the lower part of the hearth, nearly one-half of the upper portion of the bottom is uncovered, and is being heated by the flame, whereby the bottom does not chill the metal as it passes in the course of its revolution to the lowest position, and so beneath the bath of molten metal. The hearth is revolved at the rate of about four revolutiens per minute, at which rate it is driven by mechanism applied to the under side of the furnace bottom. As the hearth revolves with a newly introduced charge, the lumps of scrap are carried partially around with the hearth and then roll back into the fluid bath; in which manner fresh surfaces of the charge are being constantly exposed to the action of the heat, and melting down proceeds with a proportionately increased rapidity, whereby the smaller furnaces working upon 8 ton charges are able to work off (by the Siemens-Martin process) from three to four charges of soft metal, or from four to five charges of hard metal, during the turn of twenty-four hours, whilst the larger 20 ton furnaces melt two charges in the twenty-four hours.

PRODUCTION OF STEEL BY THE PNEUMATIC OR BESSEMER PROCESS.

The pneumatic or Bessemer process consists in the *decarburization* and fining of pig-iron by the blowing of atmospheric air through the molten metal, and then *recarburizing* the same for the production of steel by the addition of speigeleisen or of ferromanganese; the heat developed by the combustion and oxidation of the carbon, silicon, and manganese of the pig-iron, being sufficient to maintain the charge in a perfect state of fluidity, during the continuance of the process.

The original Bessemer process, as conducted in a *ganister (silicious)* lined converter, does not effect the elimination of either sulphur or phosphorus from the pig-iron; but by the *modification* introduced by Messrs. Thomas & Gilchrist, *according* to which the Bessemer process is conducted in a *basic (dolomitic)* lined converter, it is possible to eliminate the above-named elements, and so to use an inferior or Cleveland phosphoric pig-iron for the production of steel. Accordingly, the description of the Bessemer process and of Bessemer steel given throughout the present chapter has reference to the original Bessemer process, as conducted in a silicious or acid lined converter; but the similar process only carried on in a converter, or vessel lined with a basic material, such as dolomite, will be subsequently described as the *Basic Process*, and the product as *Basic Steel.*

210. Bessemer Process.—In this process the conversion of pig-iron into malleable iron or steel is effected wholly by the direct chemical action of atmospheric air upon molten pig-iron, and without the intervention of those reactions between the elements of the pig-iron and the oxides of iron and manganese which take place in the decarburization of pig-iron by the operation of puddling, which reactions appear necessary for the elimination of the elements, sulphur, phosphorus and copper, from the product; for, whereas, in the puddling operation, these elements are removed to the extent of about 75 per cent. of the amount present in the pig-iron, in the Bessemer process they are scarcely if at all affected; the percentage of sulphur in the Bessemer metal being but little reduced, while the amount of phosphorus is slightly in excess of that contained in the original pig-iron employed: not that the total amount of phosphorus has absolutely increased, but it has increased relatively, since a considerable amount of the impurities, as carbon and silicon, as also of manganese, are removed from the pig metal by the process, leaving a proportionately smaller amount of iron for combination with the phosphorus, etc. The carbon and silicon are almost entirely burnt out during the conversion; the manganese also is eliminated from the product, but its presence in the pig-iron, in the first instance, is advantageous for the production of a superior metal, since, so long as any manganese remains unoxidized, only a very small proportion of iron is oxidized by the blast; any excess of oxygen introduced being applied to the conversion of the manganese into manganous oxide, which then combines with the silica, from the silicon of the metal or silicious lining of the converter, with the formation of a readily fusible slag. From these observations it is obvious that the method can only be applied to the working of those qualities of pig-iron that are practically free from sulphur, phosphorus, and copper; of such are the irons smelted from hæmatites and magnetic ores, the demand for which class of ore has given an impetus to the mining and metallurgical industries of the North of England unprecedented in the annals of any other mining district, the Cumberland hæmatites being in special demand for conversion into steel by the Bessemer process.

In the earlier patents of Mr. Bessemer, he proposes to force air or steam, or air and steam, amongst the particles of molten pig-iron until the metal has acquired the malleability and other qualities of steel; for this purpose he introduced the blast from the top of his converting vessel by a tube or hollow rabble passing towards the bottom of the vessel, whereas, at the present time, the blast is introduced by a number of twyers through the bottom of the converter, the air passing upwards through the mass of molten metal. The use of steam, it is scarcely necessary to remark, is impracticable, since the cooling effect, due to the large absorption of heat occurring from the decomposition of the steam on its passage through the fluid pig-iron, rapidly solidifies the charge, instead of raising the temperature of the metal to the high degree necessary for the Bessemer blow, as occurs when air alone is similarly passed through the molten mass.

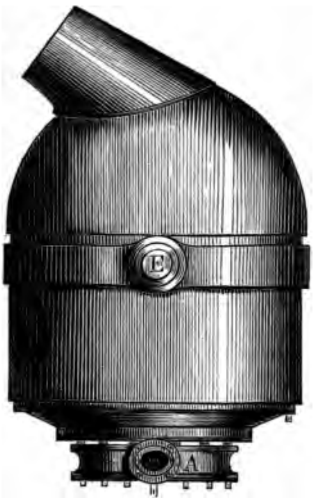

Fig. 57. — Side Elevation of the Bessemer Vessel or Converter.

The Bessemer *converter* or *vessel*, in which the blow is conducted, has the form shown *in fig. 57,* the neck or mouth inclining over at an angle of about 30° to the body of the converter, so that the flame and sparks are directed away from the workman and the casting-pit to be subsequently mentioned; also the position of the mouth prevents, to a very considerable degree, the ejection of the molten metal, which would otherwise occur during the violent disturbance attendant upon the blowing of the charge. The size of the mouth is also of importance, for if too large it is attended with a loss of heat, and part of the converted metal is apt to solidify upon, or coat the surface of the vessel; and if too small, an undue back pressure results, and the operation is retarded. The vessels are made of sizes capable of blowing or converting from 3 to 10 tons of metal at each charge, and are called respectively, 3, 4, 5—10 ton converters. A 6-ton converter is about 8 feet in height, and 12 feet 6 inches in diameter outside. The converter is formed of an outer skin or shell of wrought-iron plates, $\frac{5}{8}$, $\frac{3}{4}$, and $\frac{7}{8}$ inch in thickness, riveted together, and lined in the inside with 10 or 12 inches in thickness of a most refractory material, usually "ganister," or a layer of fire-brick may be first built in the outer shell, and this covered to a depth of a few inches with ganister. In order to line the converter, the ganister is ground to a tolerably fine powder, and either used alone or mixed with a small quantity of powdered fire-brick; the twyer box A, and the plates forming the bottom of the converter are removed, when the mouth of the vessel is closed by a piece of wood, and then turning the converter mouth downwards, a wooden core of the internal size of the converter is introduced, and the moistened ganister rammed well in between the shell of the converter and this core, after which the latter is withdrawn. The bottom of the converter is connected with the body of the vessel by bolts and cotters, its inner surface being made flat, as shown, and it is penetrated by from seven to twelve (according to the size of converter) conical clay twyers *a*, *a*, fig. 58, which in a 6-ton converter are 20 inches in length, and each containing twelve holes or apertures for the admission of the blast to the converter. The twyers are introduced from the lower side or twyer box, and carefully luted around to prevent the escape of metal into the space A. The *bottom plate* of the box A is readily removable for obtaining access to the twyers, each of which is held up in its position by a stop or horizontal arm *b*, capable of rotation to one side when it is necessary to withdraw and replace any one of the twyer bricks. The twyer box or air chamber is connected by a curved pipe *e*, elliptical in section, with the hollow trunnion E of the converter, and so with the blowing apparatus. A stout belt, hoop, or trunnion of wrought-iron, is placed around the body of the converter, the arms of which rest upon bearings in the cast-iron standards D; one arm E of this trunnion is hollow, and connected by suitable valves with the blowing cylinders; the other arm is solid, and to this is keyed a spur pinion *c*, which works into a vertical rack *d* actuated by a hydraulic piston or ram placed below, and which is under the control of the workman (vesselman)—the converter being capable of rotation in a *vertical plane* through an angle of 180°. Formerly, it was *the practice* to make the blast automatic, so that when

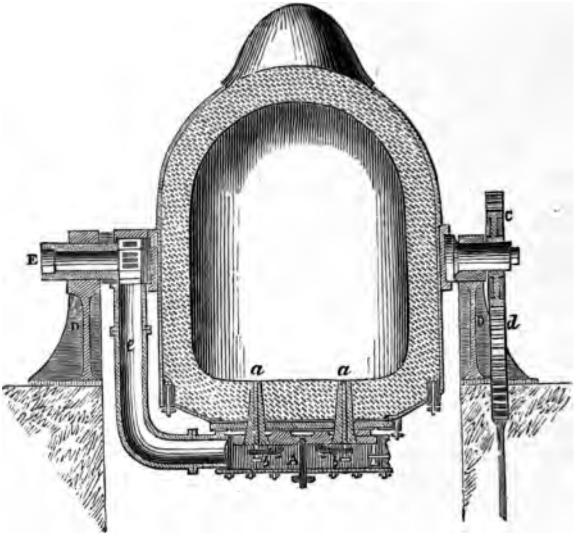

Fig. 58.—Vertical Section through the Trunnions of the Bessemer Converter.

the blow was over, and the vesselman turned down the converter for discharging its contents, the trunnion in its revolution closed the valve connected with the blast; this mechanism is, however, liable to derangement, and the blast is now generally shut off by an independent valve. When the converter is vertical, its mouth is directed towards an open rectangular space, or to a hood forming the bottom of a kind of stack, which takes away the gases and sparks thrown out from the converter during the blow.

It is usual in Bessemer steel works to place the converters in pairs, either on the same or opposite sides of a casting-pit, a small cupola or wind furnace being situated between the two for melting the charge of *speigel* to be added at the end of the blow. The cupola is raised sufficiently high to allow the speigel to be tapped directly from the furnace, into an iron trough lined with sand and which leads to either converter, or so that the speigel may be first tapped into a ladle and weighed before emptying into the converter. The casting-pit is occupied by the ingot moulds for the receipt of the metal and the apparatus for discharging the metal into these moulds. In the centre is a hydraulic lift or casting crane formed by a hydraulic piston or ram, to the top of which is attached a platform formed by a pair of wrought-iron girders well braced together; this platform receives at one end the ladle into which the metal is emptied from the converter, at the opposite end to which is a mass of iron, acting as a counterpoise to the weight of the ladle and its contents; a handle connected with the necessary gearing enables a man standing at the middle of this platform to traverse the ladle inwards or outwards, so as to bring it exactly over the centre of the ingot moulds; and by another handle or wheel he is able to rotate the crane around the pit, thereby emptying its contents into moulds placed in any part of the pit, while a third movement enables him to raise the table so as to come over moulds of varying height.

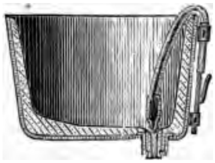

Fig. 59.—BESSEMER CASTING LADLE.

The ladle (fig. 59) resembles the ordinary ironfounder's casting ladle; it is formed of iron plates riveted together, and lined on the inside with a refractory material, as sand or ganister; but, instead of pouring the metal from a lip, it is tapped from the bottom of the ladle, for which purpose the bottom inclines from all parts to one side where the tap-hole is placed. A fire-clay nozzle attached to a vertical iron rod, also coated with fire-clay, fits into this hole, and by connecting the top of this rod with a hand lever, the nozzle can be raised or lowered so as to allow sufficient metal to escape to fill any required mould, when by depressing the lever, the nozzle or plug is reinserted and the stream is stopped until the ladle is placed over another mould. The moulds employed for casting ingots of Bessemer steel are of cast-iron, open at both ends, and octagonal, square, or circular in section, with a considerable taper from top to bottom so as to allow of the ready extraction of the ingot therefrom.

The charge of the Bessemer converter consists, as already noted, of from 5 to 8 tons of molten pig-iron, the most usual charges, however, varying from 6 to 8 tons. Previous to the introduction of the molten pig-iron into the converter (unless the vessel is already hot from a previous charge), a fire is made in the vessel, a quantity of coke thrown in, and the blast turned gently on; this is continued until the inside of the converter is at a red heat, when the vessel is turned upon its axis, so as to bring the mouth downwards, and the coke, etc., is thus emptied into the pit beneath the convertor, the blast being blown through to drive out the coke. The converter is now rotated into a horizontal position, when the charge of pig-iron, which has been melted in a reverberatory or cupola furnace placed in the vicinity of the converter, is run along a movable gutter of wrought-iron, lined with sand or ganister, into the red-hot vessel; or, according to more recent practice, the metal may be tapped directly from the blast furnace into a ladle, and from thence into the converter. Before running in the pig-iron it is not unusual to throw into the converter 10 per cent., or even 20 per cent., of the charge in the form of scrap-steel, such as rail-ends, skulls, etc., either cold or after heating to whiteness in a neighbouring furnace; in the case of light scrap it is melted down in the cupola along with the pig-iron. Owing to the shape of the converter, when in a horizontal position, the twyers are above the bath of metal thus introduced.

The blast is now turned on, and the converter is then rotated into the vertical position, the passage from the horizontal to the vertical being accompanied by the ejection of a shower of sparks and graphite blown out by the blast. On assuming the vertical position, however, during the first three or four minutes, only a small very slightly luminous flame, accompanied by sparks, is visible from the mouth of the converter; after which the flame becomes a little more luminous and unsteady, and in from eight to ten minutes the flame is very dense, yellow, bright, and considerably increased in size. The metal is now in a violent state of ebullition, showers of slag, sparks, and burning iron are frequently ejected from the mouth of the converter, while the pressure of the blast, which at first was from 15 lbs. to 20 lbs. per square inch, falls to 10 or 11 lbs.; this stage, or what is known as the *boil*, continues for from six to eight minutes, with a charge of 5 tons of metal, and towards the conclusion of this stage the flame becomes less dense, and assumes a characteristic rose or pale amethyst tint, indicating the last or *fining* stage of the blow, during which the flame is diminishing in size and intensity, and in from eighteen to twenty minutes from the commencement of the blow the flame finally *drops*, an indication that the blow is at an end. The converter is then quickly turned down into the horizontal position, the blast turned off, and from 7 per cent. to 10 per cent. of melted speigeleisen or other highly carburetted and manganiferous alloy is added to the contents of the converter, the immediate effect of which is the emission from the mouth of the converter of a long, roaring, and extremely luminous jet of flame, the appearance of which is a further indication that the blow was completed before the converter was turned over. Formerly, it was the practice to place the converter vertical, and continue the blowing for a short time after the addition of the speigeleisen, but for some time this practice has been discontinued. The metal, which is now as fluid as water, is allowed to stand for a few seconds, and is then transferred, along with a quantity of slag, from the converter to the casting ladle, the ladle having previously been heated by burning charcoal or coke within it; the slag floats on the top, and assists in retaining the heat of the fluid metal during the casting operation.

The converter is now turned mouth downwards, when the slag that had remained behind drains out into the pit below. As each ingot mould is filled with metal its surface is covered with sand, and a cast-iron plate, secured by wedges and eye-bolts to the ingot mould, is placed on the top to prevent, as far as possible, the rising of the metal on solidification, and thereby rendering the top of the ingot unsound and honeycombed.

The duration of the blow just given applies to a 5-ton blow consisting of English hæmatite pig-iron, or this mixed with only a small proportion of Swedish irons. If Swedish pig-iron be used alone, the blow is much shorter; instead of lasting from sixteen to twenty minutes, it will be over in from thirteen to fifteen minutes for a 5-ton charge; the process altogether requiring greater care that the blowing be not continued beyond the point of total decarburization by even a few seconds, otherwise considerable practicable difficulties arise from the deposition of a film or coating of metal on the inside of the converter, requiring much labour to detach it. For heavier charges of metal the time of blowing is proportionately increased, a blow of 8 tons of hæmatite pig-iron requiring from 20 to 25 minutes for its completion.

The Bessemer process, as above described, consists in continuing the blow until the charge is totally decarburized, and then restoring the necessary amount of carbon to convert the whole into steel, by the addition of an amount of speigeleisen proportional to the temper required in the product. In Sweden, however, the process was formerly conducted by stopping the blow before complete decarburization had been attained, leaving thereby an amount of carbon in the metal equal to the production of the desired temper; but the difficulty of being able to stop the process at the exact period, led to the almost general introduction of the total decarburization method as practised in England. In Styria, again, the iron employed contains from 1 to 3 per cent. of manganese, and, instead of adding speigeleisen to the converted charge, the necessary amount of carbon is introduced by the use of a quantity of pig-iron of the same kind as the original charge.

It is usual in England to stop the blow, that is, turn over the converter at the instant the flame falls; in Austria and

Sweden* the progress of the operation is judged from the character of the slag; an iron rod is inserted into the converter, and, when brought out, a portion of slag adheres to the point; so long as any carbon remains unconsumed, a peculiar brownish tint is observed, but as soon as the point of total decarburization is reached, the slag assumes a dead black colour, with a peculiar metallic lustre, due to the presence of oxide of iron.

If the blowing be continued after the oxidation of the whole of the carbon is completed, the heat is maintained by the combustion of the iron itself, and the product is deteriorated in quality, approaching in character towards burnt iron, in proportion to the extent of overblowing; at the same time it is attended with considerable loss in the yield. If much overblown, the converter, as also the sides and bottom of the ladle, are coated with a thick crust of metal; this crust, solidified, of the internal form of the ladle, is technically called a *skull*, and when produced is usually broken up and introduced with the next charge as scrap-steel. Overblowing of the metal for only a few seconds is sufficient to create a skull in the ladle of considerable weight.

About thirty charges can be worked off in the twenty-four hours from each converter. Although the actual blowing lasts only about twenty minutes, the melting of the pig-iron and removal of the ingots from the pit, with the re-arrangement of the moulds, occupy a considerable time. After five or six blows some of the twyers also require renewal, the brick being eaten down to a considerable depth below the level of the bottom. For their insertion, the bottom plate of the twyer box is removed, the old twyers are knocked out and new ones inserted from below. The twyers are then luted round, and secured as previously described, after which the converter is turned up, and a quantity of a thin paste of ganister and fire-clay is run in around the twyers on the inside of the bottom. After about eighty blows the converter usually requires relining, frequent repairs of the lining having been effected in the meantime by ramming patches of ganister on the more corroded and broken down parts of the lining.

Besides the twyers the bottom of the vessel itself rapidly wears away, and requires renewal after from ten to twenty blows, or sometimes even less; hence, in order to make the large number of blows per day which are now made, especially in America, it is necessary to have some more rapid manner than that just described for the renewal or changing not only of a set of twyers, but of the entire bottom of a converter, without delaying unnecessarily the work of the Bessemer casting-pit. Accordingly, instead of the fixed bottom, as already described, the late Mr. Holley devised a vessel with a "*movable bottom*," which is now generally used in all the newer works. By this application an old bottom can be taken out of a converter and a new one reinstated ready for working, under a delay of less than an hour, and this without cooling the interior of the vessel below a red heat. With the Holley movable bottom, fig. 60, it is unnecessary to run into the interior of the vessel any paste of ganister (slurry), to make good the junction around the joint of the bottom or around the twyers, and hence the vessel is not cooled down from that cause, as occurs with the fixed bottom. The movable bottom is built up, and thoroughly dried before being required for use, and it is attached to the body of the converter when required by pins and cotters. The edge or periphery of the movable bottom is bevelled off approximately to an angle of 45°, so that when the bottom already prepared is lifted (by means of an hydraulic lift standing below the converter) into its position, an open wedge-shaped annulus, *a*, is left around the junction of the bottom and the body of the vessel, but this is filled up and made tight by ramming in cakes of ganister from the outside.

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* Bauerman.

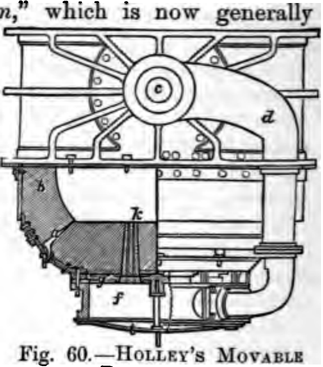

Fig. 60.—Holley's Movable Bottom.

In some works, for still further increasing the output and economy of the process, duplicate converters are made, which are lined, dried, and heated up, before being placed in position, so that when a converter requires relining, instead of stopping the plant and cooling down the converter for relining in position, the converter is constructed so that, after removing sundry knuckle pieces and pins, the vessel can be lifted from within the trunnion ring, by suitable cranes or lifts, and a new vessel at once inserted in its place, which, after properly securing to the trunnion ring, is ready for work.

The total yield of Bessemer metal produced averages from 80 to 85 per cent. of the total weight of pig-iron and speigeleisen introduced into the cupola or other remelting furnace.

The decarburized metal obtained at the termination of the blow, and before the addition of speigeleisen, behaves on mechanical treatment exactly as burnt iron; it is found to be exceedingly *red-short*, that is, cannot be welded or hammered at a red heat, but crumbles and falls to powder on attempting to work it under the hammer; this rottenness or want of cohesion in the product is generally allowed to be due to the presence of a surplus of oxygen and silicon in the intensely heated metal, which elements are removed by the addition of *speigeleisen* or other alloy rich in manganese, owing to the very powerful affinities of oxygen, silicon, and manganese for each other, whereby the three pass out as a fusible slag, and the metal has restored to it all the qualities of good steel, the hardness of temper depending on the amount of carbon introduced in the manganiferous alloy.

211. Decomposition in the Bessemer Vessel or Converter.—The following analyses* of the pig-iron employed, steel produced, and of the metal at various stages of the process, as determined at the Austrian works of Neuberg, and by Mr. Snelus at the Dowlais works, show that during the first stage of the process the operation is attended with the conversion of the *graphite* into *combined carbon*, and also by a very considerable diminution in the amount of silicon, thus indicating that the *silicon* is burnt off in the earlier stages of the blow much *more rapidly* than the *carbon*, while in the last stage of the process the action is reversed, the carbon being very rapidly oxidized and eliminated, whilst the silicon at the same time does not suffer any very material change. The analysis of the slag produced at this same period, No. II., shows that the manganese is being rapidly oxidized, the oxide so formed combining with silica, with the formation of a fusible silicate or slag; while in the same period the iron is comparatively unaffected. During the boil the carbon, silicon, and manganese, as indicated by the analysis No. III., are suffering combustion, whilst at the conclusion of the last or fining period, there is present in the metal but a few hundredths per cent. of these elements (No. IV.), and the corresponding analysis of the slag indicates a sudden increase in the amount of iron, showing that at the end of the boil the manganese is practically removed, and that during the fining or last stage of the process, the iron begins to suffer oxidation and waste. No. V. is the analysis of the Bessemer steel produced after recarburization by the addition of the speigeleisen, in which it is also noticeable that the percentage of phosphorus and sulphur differs but slightly from the amounts shown in the analysis of the original pig-iron.

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* *Journal of the Iron and Steel Institute.* Paper by Dr. Roscoe, 1871.

The *slag remaining in the Bessemer converter*, after teeming the metal into the ladle, is a heterogeneous, porphyritic-looking, silicious mixture, consisting of a fused portion or flux, forming the true slag, enveloping and cementing together large quantities of apparently infused quartzose matters, derived from the sides of the converter, etc. The composition of this slag or residue is accordingly exceedingly various, from the varying quantities of ganister, etc., detached from the lining of the converter in different blows; but analysis of the fused portions at different stages of the blow, as given on the succeeding page, afford tolerably accurate indications of the progress of the blow, and of the decompositions proceeding in each stage. The physical qualities of the fused slag also differ as the blow advances towards completion; thus, the fused slag has at first more or less of a lemon colour, becoming successively orange, light-brown, dark-brown, and black, as the carbon is removed from the charge, and these characteristics form the basis upon which *the slag test* for the conduct and stoppage of the blow (as *sometimes* pursued in Austria and Sweden), is founded.

ANALYSES OF THE METAL TAKEN FROM THE CONVERTER AT DIFFERENT STAGES OF THE BLOW AT THE NEUBERG WORKS.

	I.	II.	III.	IV.	V.
Graphite, ...	3·180	...	...	...	...
Combined carbon,	0·750	2·465	0·949	0·087	0·234
Silicon, ...	1·960	0·443	0·112	0·028	0·033
Sulphur, ...	0·018	Trace	Trace	Trace	Trace
Phosphorus, ...	0·040	0·040.	0·045	0·045	0·044
Manganese, ...	3·460	1·645	0·429	0·113	0·139
Copper, ...	0·085	0·091	0·095	0·120	0·105

ANALYSES AT THE DOWLAIS WORKS.

	I.	II.	III.	IV.	V.
Graphite, ...	2·07	...	...	...	...
Combined carbon,	1·20	2·127	1·55	0·097	0·566
Silicon, ...	1·952	0·795	0·635	0·020	0·030
Sulphur, ...	0·014	Trace	...	Trace	...
Phosphorus, ...	0·048	0·051	0·064	0·067	0·055
Manganese, ...	0·086	Trace	...	Trace	0·309
Copper, ...	...	...	...	...	0·039

ANALYSES OF SLAGS PRODUCED AT DOWLAIS.

	II.	III.	IV.	V.
Silica, ...	46·78	51·75	46·75	47·27
Alumina, ...	4 65	2·98	2·80	3·45
Iron protoxide, ...	6·78	5·58	16·86	15·43
Manganese protoxide,........	37·00	37·90	32·23	31·89
Lime, ...	2·98	1·76	1·19	1 23
Magnesia, ...	1·53	0·45	0·52	0·61
Alkalies, ...	Traces	Traces	Traces	Traces
Sulphur, ...	0·04	Traces	Trace	...
Phosphorus, ...	0·03	0·02	0·01	0·01

I. Original pig-iron.
II. Metal and slag taken at the end of the first period (6 minutes).
III. ,, ,, boil (12 minutes).
IV. ,, ,, blow
V. After addition of speigel.

Mr. Snelus, in a paper to the Iron and Steel Institute, communicates the following as the composition of the gases escaping from the mouth of the converter during a blow lasting eighteen minutes:—

	I.	II.	III.	IV.	V.	VI.
Carbonic anhydride,	10·71	8·59	8·20	3·58	2·30	1·34
Carbonic oxide,......	None	3·95	4·52	19·59	29·30	31·11
Oxygen,................	0·92	...	...	...	...	..
Hydrogen, ...	88·37	0·88	2·00	2·00	2·16	2·00
Nitrogen, ...		86·58	85·28	74·83	66·24	65·55
	100·00	100·00	100·00	100·00	100·00	100·00

I. Taken 2 minutes after the commencement of blow.
II. ,, 4 ,, ,, ,,
III. ,, 6 ,, ,, ,,
IV. ,, 10 ,, ,, ,,
V. ,, 12 ,, ,, ,,
VI. ,, 14 ,, ,, ,,

These analyses show that during the first period of the blow, when the temperature is low, and only a very small slightly luminous flame is visible at the mouth of the converter, that the carbon is oxidized to carbonic anhydride; but as the process advances, and the temperature rises, the proportion of carbonic oxide to carbonic anhydride rapidly increases. Analysis IV., taken ten minutes from the commencement or after the boil has commenced, shows a very large increase in the amount of carbonic oxide gas, attended with a corresponding decrease in the proportion of carbonic anhydride. At this period the flame has considerably increased in size, and presents the reddish-violet tinge characteristic of burning carbonic oxide. From this time to the end of the blow the proportion of carbonic oxide to carbonic anhydride continues to increase.

From the experiments of I. L. Bell, Esq., it appears that at very high temperatures, carbonic acid is more stable than carbonic anhydride when in contact with metallic iron, and this may account for the presence of carbonic anhydride in the earlier and cooler stages of the process, whilst, as the temperature increases, its place is taken by carbonic oxide.

Mr. Snelus has computed that the heating power of the gases (chiefly carbonic oxide) escaping from the converter towards the end of the blow is, in works blowing 1000 tons of pig-iron per week, equal to the effect produced by a consumption of 25 tons of coke per week.

Dr. W. M. Watts has attempted to determine the temperature of the flame of the Bessemer converter, and he finds that at the commencement of the blow, a wire of gold held in the flame does not melt, whilst towards the middle and end of the blow, the gold was always melted; hence he concludes that the temperature of the flame at the commencement is below 1300° C. (the melting point of gold). An alloy of platinum and iridium, or platinum alone, does not melt at any period of the process; hence, taking the melting point of platinum at 2000° C., it follows that the temperature of the flame, although increasing beyond 1300° C., never attains to 2000° C.

212. Bessemer Pig-Iron.—The essentials in a pig-iron applicable to the Bessemer process are:—1° almost absolute freedom from sulphur, phosphorus, and copper, since these elements are not sensibly diminished in amount by the Bessemer process; 2° the presence of a minimum of about 2 per cent. of silicon in pig-irons containing only very small amounts of manganese; for though in this proportion it is almost entirely removed during the process, yet its high calorific power—about 7000—renders it valuable as a heat producer, and thus aids in preventing the loss by the production of *skulls*, which takes place when this element is present in insufficient amount; if present in too large proportion, however, the whole of the carbon may be oxidized and eliminated, while sufficient silicon still remains in the metal to deteriorate its quality, about one-tenth per cent. of silicon being sufficient to make Bessemer steel hard and brittle when cold; the presence of an excess of silicon in the pig-iron is also attended with an increased waste of iron in the form of slag; 3° the pig should be of No. 1 or No. 2 in greyness, for the use of white iron is attended with difficulty and loss; its carbon being in the combined state is converted into carbonic oxide in the earlier stages of the process, before the necessary heat of the metal has been attained, and the combustion of the silicon effected; and 4° the presence of manganese in the pig-iron is advantageous, for although entirely removed, so long as any remains in the molten bath of metal, it prevents the oxidation and waste of iron; and acting as a heat producer, is especially desirable therefore in pig-irons low in silicon. Jordan sets down the minimum of manganese at 1 per cent., but this is considerably in excess of what is used in England, where the pig-irons employed are usually highly siliceous. Mixtures of pig-irons are generally preferred for the Bessemer process, rather than the use of a single class of iron.

213. Application of the Spectroscope.—The spectroscope has been applied somewhat extensively on the continent, and to a lesser extent in England, for the analysis of the Bessemer flame, and the determination of the point of total decarburization or point at which the blast should be turned off. It is especially useful where different irons are being continually blown, with the behaviour of which the workman is not familiar. The phenomena, as observed by the naked eye, and through the spectroscope, in a blow of 4½ tons of metal, chiefly hæmatite pig-iron, are tabulated below.

In blowing Swedish pig-irons, which are low in silicon, and contain from 1 to 3 per cent. of manganese, the boil commences sooner than when hæmatites are the subject of operation, and the spectrum appears earlier, the yellow line flashing in about thirty seconds, and has become steady or fixed, in from one to one and a half minutes from the commencement of the blow; after which, at about the same intervals as in last case, the other appearances occur, the blow being completed for this charge in about twenty-one minutes. The spectrum is not, however, usually so clear, due to the cloud or haze of brown vapour or smoke which ascends from the mouth of the converter when manganiferous pig-irons are under treatment; the spectrum at the same time is generally less complicated, a number of lines in the green and blue portion of the spectrum of the hæmatites being absent.

214. Bessemer Process with Fixed Converter.—Instead of the converter resting on trunnions, and having a move[illegible]t in a vertical plane to enable it to receive its charge,

Time from Commencement.	Appearance to the Naked Eye.	Appearance of the Spectrum.
4 minutes.	Very small flame, with sparks of metal.	Faint continuous spectrum.
5 „	Pale flame, increasing in size.	Continuous spectrum, with two yellow sodium lines D, flashing across the spectrum.
6 „	Flame large, but very unsteady.	Sodium lines have become steady, and fixed.
8 „	Flame much brighter and larger.	Yellow sodium lines, with lines in the red and violet ends of the spectrum appear.
10 „	Flame is very bright and dense; the boil has commenced.	The last spectrum remains with additional lines in the red, also carbon lines in green and blue, with green * manganese oxide lines
15 „	Flame is larger, but more transparent.	Lines in the spectrum more distinct, and better defined.
20 „	Flame diminishing in size, and not so luminous.	Spectrum fading.
24 „	Flame drops, and blow is over.	The green lines of carbon and manganese disappear.

* Dr. W. M. Watts.

and to empty out the finished product, as described in the preceding pages, the use of a *fixed converter or vessel* is being revived by Messrs. Clapp & Griffiths with some reported success. The Griffiths' converter consists of an upright open-topped vessel, formed in three parts; an upper part forming the stack or head of the vessel; a middle ring or bosh around which water is circulated to keep it cool, whilst the third or bottom part, has a flat bottom and low vertical sides. The bottom is carried upon a frame which can be raised or lowered in another frame. The whole apparatus is lined with refractory materials, like the ordinary converter, but the bottom and middle pieces of the converter need not fit accurately but may stand apart for a short distance to allow of any irregularities in the edges of the lining of the two parts.

Around the sides of the lower portion or bottom of the vessel are six twyer boxes, and as many *horizontal twyers*, through which the blast, under a pressure of only about 5 lbs. per inch, is delivered, at a short distance above the bottom plate. The blast passage through each twyer is closed by a suitable stopper, driven home by steam or other mechanical contrivance, whereby the entrance of the fluid metal into the blast boxes is prevented when the blast is shut off. A door on each blast-box can be opened, and a twyer-block and new twyer can be inserted after withdrawing an old one, without necessitating any stoppage for the cooling down of the apparatus. At the lowest point of the side of the vessel is the tap hole, which is stopped as usual, and fitted with the usual spout or lander for conveying the metal from the converter to the ladle.

A little above the level of the molten charge is a door, or in lieu thereof, two or more smaller openings are left at different vertical heights above the metal, and these serve for the introduction of the charge of fluid pig-iron and for raking off the slag, etc., from the top of the metal within the vessel.

The process with the fixed vessel is conducted in the same manner as the ordinary process; but the pressure of blast required with this arrangement is lower than is necessary with the regular Bessemer converter, and the whole plant is considerably less costly than the ordinary apparatus.

215. The Basic Process for the Production of Steel from Phosphoric Pig-Iron.—For the successful conduct of the Bessemer process in ganister (silicious) lined converters or vessels, only hæmatite, or such other pig-irons as are practically free from phosphorus, are available; but by conducting the process, after the manner carried out successfully by Messrs. Thomas & Gilchrist, in the so-called "*dephosphorization*" or "*basic process*," in which the vessel or converter is lined with a highly *basic material*, such as suitably prepared *dolomite* or magnesia, then pig-iron containing from 1 per cent. to 3 per cent. of phosphorus, such as that produced by the smelting of spathic and other ores in the Cleveland district, and upon the Continent, can be successfully treated in the converter for the production of "*basic steel*," especially of the softer tempers, as required for plates, rails, etc.

The details for the practical conduct of the basic process differ somewhat, as will be presently indicated, from the methods observed in the ordinary Bessemer process, and more especially in *continuing the blow for some two or three minutes beyond the point of decarburization* at which the blast is invariably shut off in the ordinary Bessemer process.

The *basic lining* above mentioned is alike applicable to the Siemens open-hearth melting furnace, as well as to the Bessemer converter, its use in the former being attended with the same result as in the Bessemer converter, viz., that Cleveland or other phosphoric pig-iron can then be used for the production of steel, but as yet the basic process has not been extensively adopted with the Siemens furnace, although large quantities of *basic steel* are now regularly produced by the basic Bessemer process.

The *lining* employed in the *basic or dephosphorizing process* must be strongly basic, and also capable of resisting the high temperature of the Bessemer converter without softening or melting. Such a material is found in *dolomite* or *magnesian limestone*, which substance is for this purpose either made into bricks which require to be first very strongly burnt, and then built into the body of the converter with a cement of anhydrous coal tar, or, as is more general, the dolomite is ground to powder, then very strongly burnt, and when cold is mixed with *coal tar*, which has previously been boiled to expel any water. The mixture is then rammed into the space between the shell of the converter, and a hollow cast-iron model or plug having the internal size and form of the converter. The plug is often previously heated by making a coke fire within it, so that during the ramming up of the lining, the materials assume a more or less plastic condition, and retain the desired form when the plug is withdrawn.

The *basic process* may be conducted with the ordinary Bessemer vessel and plant, with the exception that the vessel is lined as above with a dolomite or other basic lining, instead of with the ganister or silicious lining; but where new plant has been put down for the basic process, then the converters have been made shorter but larger in diameter than the ordinary vessels, and the neck also, instead of standing at an angle with the body is made concentric with it, so as to admit of the molten cast-iron being introduced into, and the steel poured from the converter, upon either side of the same, whereby the corrosive action of the slags upon the lining of the vessel is made more equal on the two sides and the duration of the lining is thereby prolonged. Owing to the highly corrosive action of the slags, and the more rapid destruction of the lining in the basic process, repairs are therefore more frequently required, and the application of loose bottoms, and of interchangeable converters, is more necessary and general than when the ordinary or acid process is pursued. The loose bottom for the basic process is generally covered to a thickness of about 2 feet with the same materials as the body lining, and it is rammed up on the bottom plate with a number of spikes of about half-inch in diameter standing above the surface of the dolomite, so that, on withdrawing the plate and spikes a series of passages are left through the bottom, which act instead of twyers for the admission of the blast.

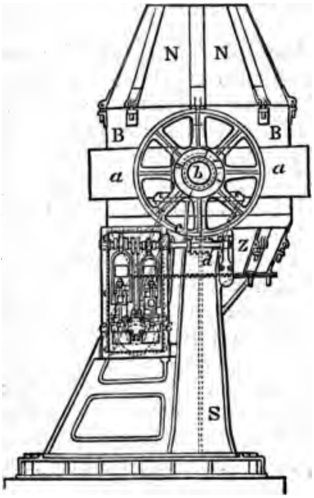

Fig. 61. Elevation of the Converter for the Basic Bessemer Process*.

The more recent converters (fig. 61) built for the basic process are made in four parts, the body, the conical neck, the bottom, and the trunnion ring, and these are coupled together by bolts and cotters to form the complete vessel. The body B for a 10-ton vessel, is made of one-inch iron plates, which are rivetted together and strengthened by suitable straps.

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* *Proceedings of the Institute of Civil Engineers, 1881.*

The neck N is also of iron plates, and is detachable so as to be lined up separately before putting into position for use. The bottom Z, with twyer box, etc., is rammed up separately, as already noted, whilst the trunnion ring or belt *a*, and the arms *b*, *b*, are made in cast-iron of box section. The tipping gear consists of a large worm wheel *c* attached to one arm of the trunnion ring, and into this wheel gears a screw or worm *d* of 4½ inches pitch, which worm is driven by a pair of small double-acting hydraulic engines carried on the same standards as the vessel itself. The vessel can thus be rotated through 360° in either direction. The casting pit is of the most approved Bessemer type, and is fitted with the usual cranes, as described (page 249).

In commencing work with a freshly-lined converter, the operation begins by first thoroughly warming up the vessel, and then introducing into the vessel well *burnt lime*, to the extent of 15 or 20 per cent. of the weight of the pig-iron to be charged; a little coke-breeze is at the same time added, after which a gentle blast is passed through the converter until the whole attains to a red heat. The converter is now revolved into the horizontal position, whereupon the blast is shut off, and the charge of from 7 tons to 15 tons of molten phosphoric pig-iron (p. 272), is delivered as hot as possible, either direct from the blast furnace into the vessel, or after re-melting in a cupola. The blast is now again turned on, and the vessel is revolved into the vertical position, when the phenomena attending the ordinary Bessemer process, as already detailed, are observed, until the point of total decarburization is attained. This stage is reached after an interval of from thirteen to twenty-five minutes, exactly as in the ordinary or acid Bessemer process; but with the basic process, instead of turning down the converter, according to the ordinary Bessemer practice, the blowing is further continued in order to eliminate the phosphorus from the metal; for, as will presently be shown, the *dephosphorization* of the charge is almost wholly effected during this *after* or *over-blow* stage of the process.

During the *after* or *over-blow*, which usually lasts from two minutes to three minutes, red fumes appear at the mouth of the converter; these fumes are at first slight, but become more dense towards the end, whilst the temperature of the charge also rises during the same period, until it finally attains to about 1800° C.

Before the after-blow is judged to be quite completed, the converter is turned down with its mouth horizontal, and samples of the charge are withdrawn in a small ladle or spoon, the metal so withdrawn being cast into a small ingot, which is then hammered out, under a small steam hammer, into a small cake. The *sample* is then cooled in water and broken across, when, if the fracture presents large and bright crystals, the process is judged to be incomplete, and the converter is turned up and the blowing resumed for another minute, or may be less, according to the judgment of the workman, after which the operation of sampling is repeated, in the same manner and as often as necessary, until the metal shows the desired malleability, ductility, and smaller crystalline texture indicative of almost complete dephosphorization of the charge. One, two, or three samples are often taken during the after-blow stage of the process; but very often a single sample will suffice to indicate that a few more seconds blowing only is required to effect the desired dephosphorization, and therefore the time for the stoppage of the blow.

At the conclusion of the after-blow the method of procedure varies slightly in different works; but in most works the recarburization of the metal is effected by adding the molten speigeleisen at once to the converter, whilst a little ferromanganese in the solid state is thrown into the ladle. In other works, before adding the speigeleisen a large proportion of the slag in the converter is first run off, so as to prevent the possibility, after the blowing has ceased, of a small proportion of the phosphoric anhydride, now contained in the slag, being again reduced by the action of the molten metal, and so re-introducing a small proportion of the phosphorus into the metal within the converter.

Instead of recarburizing the metal in the converter directly by the addition of speigeleisen, as last described, another modification is also pursued in England, according to which, after the completion of the after-blow, the metal and slag are transferred from the converter to the ladle, when a proportion of molten hæmatite pig-iron is added to the ladle, by which addition a state of violent ebullition is induced, during which the slag usually overflows the sides of the ladle. As soon as this agitation ceases, the metal again subsides, whereupon a small quantity of speigel, or of ferromanganese, is added to the ladle to complete the desired recarburization of the metal.

The metal having been thus recarburized by the addition of speigeleisen and ferromanganese, by either of the last described methods, it is then poured into the ladle, and subsequently cast into ingots in the manner of the ordinary Bessemer arrangement already described.

As is shown (p. 272), the phosphoric pig-iron for treatment by the basic process ought not to contain more than from 0·5 per cent. to 1·0 per cent. of silicon; but for the treatment of such phosphoric pig as contains more silicon than this limit indicates, the so-called "*transfer method*" of treatment has been proposed and used on the Continent, although it has now been generally abandoned.

According to the "*transfer method*," the pig-iron is partially desilicized by blowing it for ten minutes or fifteen minutes in an ordinary ganister-lined converter, according to the regular Bessemer process. In this manner a large proportion of the silicon is removed (see Analyses, p. 257), and such partially desilicized metal is then transferred to a basic-lined vessel already heated and waiting for its reception. Care is taken to keep back from the basic-lined vessel, as much as possible of the silicious slag produced during the blow in the ordinary vessel. The decarburization and dephosphorization is then completed by blowing the metal for three or four minutes, as may be required, in the basic-lined converter after the manner already described.

The daily *output* or *yield* of metal from a pair of basic-lined converters is very much less than with the ordinary or ganister-lined vessels, since with the first mentioned the wear of the lining is very great, so much so, that although the more recent converters are made without lips, so as to be able to receive and teem the metal as may be required from either side of the converter, instead of always from the same side, as *is necessary* with the inclined neck and ordinary shape, thus rendering the wear of the lining more uniform on the two sides of the vessel; but notwithstanding this, each basic vessel requires to be relined after about sixty blows, for the lining is never allowed to get below some three or four inches in thickness before relining is effected. The bottoms also do not last on the average more than eleven blows before requiring to be renewed; but where loose twyers are employed, and are inserted as may be required, then twenty or thirty blows are obtainable before a new bottom becomes imperative. It is thus found that from eighteen to twenty blows per day of twenty-four hours is all that can yet be made from a basic-lined vessel. The yield of metal at each blow amounts to about 85 per cent. of the charge of pig-iron introduced into the vessel, being thus about 5 per cent. less than the yield from the ordinary Bessemer charge.

It is obvious from the above remarks, that to produce the same amount of metal with the basic process that can be made in an ordinary Bessemer plant, will require a larger number of converters, whilst the means of rapidly changing both converter bottoms and the vessels themselves are more necessary, because more frequently required, than with the ordinary process.

The economy effected in the Bessemer process by taking the metal direct from the blast furnace, instead of remelting the same in the cupola, apply in the same degree when applied to the basic process.

The *reactions* which occur *in the basic-lined converter* up to the period of total decarburization of the charge, are identical with those which take place in the ganister-lined or ordinary Bessemer vessel—that is to say, that the silicon, manganese, and carbon begin to burn off almost from the commencement of the blow in the manner described (p. 255), whilst the phosphorus remains practically unchanged up to this period, or as long as any silicon remains in the charge; but during the after-blow in the basic-lined vessel, the phosphorus is rapidly oxidized and eliminated from the metal, although the carbon and silicon during the same period do not practically suffer any further reduction. Thus at Eston,* by blowing in a basic-lined converter a charge of pig-iron containing 3·57 per cent. of carbon, 1·70 per cent. of silicon, and 1·57 of phosphorus, the ordinary blow, or total decarburization stage, was reached in fourteen and a half minutes, when the metal contained 0·07 per cent. of carbon with a trace of silicon, whilst the phosphorus still amounted to 1·22 per cent. By continuing the blast, or overblowing the metal for a further period of two minutes and five seconds, the charge then yielded on analysis only 0·08 per cent. of phosphorus with a trace only of carbon, the silicon at the same stage being nil.

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* Proceedings of the Inst. of Cleveland Engineers.

ANALYSES OF THE CHARGE AT VARIOUS STAGES OF THE BASIC BESSEMER PROCESS.

	Original Pig-iron.	After blowing for 5 minutes.	After 10 minutes' blowing.	After 15 minutes, or at end of ordinary blow.	In 18 minutes, or at end of after-blow.
Carbon..........	3·50	3·55	2·35	0·07	trace
Silicon..........	1·15	0·50	0·09	trace	——
Manganese	0·71	0·56	0·27	0·12	trace
Phosphorus....	*1·57*	*1·60*	*1·43*	*1·22*	*0·08*
Sulphur.........	0·16	0·14	0·13	0·12	0·10

That during the first stages of the Bessemer process, even in a basic-lined converter, the carbon should be thus oxidized as seen above, whilst no appreciable oxidation of the phosphorus is effected is probably due to the superior affinity of carbon for oxygen, over that of phosphorus for oxygen, under the conditions of the Bessemer converter. The same remark applies to the oxidation of iron during the process, the oxidation of the iron being very small except during the latter stages of the process, and after the carbon has been almost entirely eliminated from the charge.

For *the elimination of phosphorus* from pig-iron during the Bessemer or Siemens process, it is necessary that the *slag* produced in the process *should be highly basic*, since phosphoric anhydride P_2O_5 can only exist in the furnace or converter when it is in combination with a powerful base, such as ferrous or calcic oxide, and therefore the presence of any excess of *silica must be avoided*, since if such be present, it immediately converts any calcic or ferrous phosphates into their respective silicates, with the liberation of phosphoric anhydride from its combination with these bases. The free phosphoric anhydride would then immediately suffer reduction (at the temperature of the converter) by carbon or even by the iron itself, and so pass back into the metal instead of passing out with the slag. Instead of being separated from its combination with ferrous or calcic oxide, as above, it is more probable, that in the presence of an excess of silica, such as exists in a ganister-lined converter, any phosphoric anhydride which might be formed by the oxidation of the phosphorus in the pig-iron, would never come into contact with the ferrous oxide required to produce a stable compound with it, since the ferrous oxide, immediately it was formed by the oxidation of any iron, would combine with silica to the production of ferrous silicates, and the phosphoric anhydride, if formed, would thus be left to suffer immediate reduction by carbon. Hence, during the Bessemer process, as conducted in the silicious (ganister) lined converter, phosphorus cannot be removed from pig-iron; but with a basic (dolomitic) lined vessel, the slag produced is highly basic, and phosphoric anhydride, immediately it is formed, combines either with lime (calcic oxide), or with ferrous oxide, to the production of calcic and ferrous phosphates, which are not again reduced; so that the phosphorus once oxidized is then carried off in the slags, leaving the basic steel proportionately dephosphorized.

After the addition of the speigeleisen to the metal in the basic-lined converter, it is found that the basic steel contains not only an increased proportion of carbon, silicon, and manganese, due to the direct addition of these elements, as contained in the speigeleisen itself, but that the amount of *phosphorus* is also increased beyond that due to the amount directly introduced by the speigeleisen, and hence there is reason to suppose that probably a reduction takes place (in the interval between the addition of the speigeleisen and the casting of the ingot of metal) of a small amount of phosphorus from the slag which covers the fluid metal as it stands in the ladle.

216. **Slags from the Basic Process.**—The *slags* produced during the conduct of the basic process, although small in quantity during the earlier stages of the blow, increase towards the end of the process, and at the close of the blow the pure or fused slag forms about 20 per cent. of the weight of the steel produced, or nearly double the amount of what is produced during the conduct of the ordinary Bessemer process. Also, whilst the ordinary Bessemer slags are highly silicious mixtures, the slags from the basic-lined converter are highly basic silicates of lime and magnesia, containing notable proportions of phosphoric anhydride and ferrous oxide, but the proportion of silica in these slags does not exceed one-half of the amount contained in the ordinary Bessemer slags.

The basic slags vary much in composition at different periods of the blow, but invariably the proportions of phosphoric anhydride and of ferrous oxide are very small during the earlier stages, increasing towards the close, and especially during the period of the after, or over-blow. Thus two samples of slag from the same charge, but one taken at the end of the ordinary blow, or just at the commencement of the after-blow, and the other taken at the conclusion of the after-blow, yielded respectively 5·66 per cent. and 16·03 per cent. of *phosphoric anhydride;* in like manner, the *ferrous oxide* in the first mentioned amounted to 6·15 per cent. of the slag, whilst in the second it amounted to 12·35 per cent. Analyses of the slags taken at the end of the dephosphorization stage or after-blow of the process, show an average composition of about 10 per cent. of silica, from 10 per cent. to 15 per cent. of phosphoric anhydride, 10 per cent. of ferrous oxide, and from 40 per cent. to 50 per cent. of lime and magnesia, with smaller but variable proportions of manganous oxide.

Owing to the large proportion of phosphoric anhydride in these slags, it has been proposed to separate the calcic phosphates from such slags, and to use them as fertilizing agents. Two factories are at work in Germany for this purpose, but only a partial success has as yet attended their working.

217. Pig-Iron for the Basic Process.—The pig-iron for use in the basic Bessemer process requires to have a low content of *sulphur*, since the proportion of this element in the steel produced by the basic process is not materially less than that contained in the original pig-iron. Hence from 0·05 per cent. to 0·15 per cent. represents the usual proportion allowed, but the superior limit is only permissible either in the basic or in the ordinary Bessemer process, when rich speigel or ferromanganese is used for recarburizing the steel, whereby a larger proportion of manganese can be introduced into the steel to neutralize the sulphur, without at the same time too highly carburizing the metal.

Unlike the ordinary Bessemer requirements (page 259), a comparatively large proportion of *phosphorus* and *manganese* is preferred in the pig-iron for the basic process, with a comparatively low percentage of *silicon*. But with respect to the last mentioned (silicon), if it be entirely absent or very low, then the blow becomes slow, and the temperature attained in the converter is deficient, hence a small proportion of silicon is necessary; but highly silicious pig is to be avoided, since it is very destructive to the basic lining, and produces an excessive amount of slag, besides prolonging the duration of the blow, and increasing the waste of iron in the process.

Average samples of the pig-iron preferred for the basic process contain from 0·5 per cent. to 1·00 per cent., or 1·5 per cent., of silicon. The *manganese* usually amounts to from 1·0 per cent. to 2·0 per cent. in these pig-irons, and it is desirable to this extent, as tending by its presence to a better elimination of sulphur during the conversion; and further, the after-blow is often productive of an inferior metal of uncertain temper when the proportion of manganese present in the pig-iron is too small. But the most salient difference between the pig-iron for use in the basic and in the ordinary Bessemer process respectively, consists in the large proportion, from 1 per cent. to 3 per cent. of *phosphorus*, which is required in the metal for conversion by the first-mentioned process. The higher limit of phosphorus last quoted is even preferred for the basic process, whilst, as previously noted, for the ordinary Bessemer process, only hæmatite pig-irons practically free from phosphorus are available. Phosphorus being thus desirable to a comparatively large amount in these pig-irons, it is not unusual to mix tap-cinder with Spanish ores in the blast-furnace smelting mixture, for the production thereby of a cheap phosphoric pig-iron suitable for conversion into steel by the basic process.

The high temperature attained by the charge during the ordinary (acid) Bessemer blow is dependent upon the oxidation or combustion of silicon, manganese, and carbon; but when phosphoric pig-iron is treated in the basic lined converter, besides the elements silicon, manganese, and carbon just recited, the *phosphorus* has to be considered as a heat-producing element, since it is chiefly to the high calorific power (5747 units centigrade) of phosphorus that the very high temperature attained in the after-blow of the basic process is due. As the temperature during the ordinary Bessemer blow is largely dependent upon the proportion of silicon in the pig-iron, so in the AFTER-BLOW of the basic process the temperature is higher, and the red smoke which issues from the mouth of the converter, during the same period, is more dense and copious when the proportion of phosphorus in the pig-iron is greatest.

PRODUCTION OF SOUND CASTINGS, THE WHITWORTH PROCESS FOR COMPRESSING FLUID STEEL, STEEL-FACED ARMOUR, ETC.

Bessemer or other steel ingots, especially of the softer tempers, when cast in moulds in the ordinary manner, are always open and spongy along the centre line, and present a more or less honeycombed character, especially towards the top of the ingot (fig. 62); if, however, the ingot be cast under the pressure of a very considerable head of metal, the lower portion may be sound, but the upper portion is still honeycombed or vesicular in structure.

As previously stated, molten steel occludes, dissolves, or absorbs a considerable volume of certain gases, which gases are again to a large extent evolved as the metal changes from the liquid to the solid state; but since the skin of the ingots is necessarily the most rapidly cooled and the first to solidify, it follows that the escape of these gases from the mass is in a large degree prevented, and the gases necessarily collect throughout the steel ingot, but especially towards the upper end, and produce thereby the honeycombed structure just mentioned.

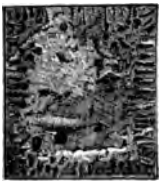


Fig. 62.—CROSS SECTION OF THE UPPER END OF A BESSEMER INGOT.

The increase in volume due to the evolution of the gases and their efforts to escape, is often manifested in the softer tempers of metal by the rising or boiling of the metal within the mould in a few seconds after the casting operation; but the honeycombed structure also frequently presents itself even when no rising of the metal has been observed.

The honeycomb or unsoundness abovementioned can be mitigated by careful *dead-melting* of the metal; by teeming the steel at higher temperatures and in a carefully regulated stream; by the addition of *silicon* (in the form of silicoferromanganese), to the metal immediately before teeming in addition to, or in lieu of a portion of the speigeleisen usually added; *by external pressure* applied through a solid hydraulic plunger upon the top of the fluid metal (Whitworth's process); by the *use of gaseous pressure* as by steam or carbonic anhydride; by the *stirring of the metal* in the ladle before casting, or by the *rapid rotation of the moulds* upon a revolving table during the solidification of the metal.

218. Silicon Steel.—The use of silicon in the form of a highly silicious ferromanganese was introduced successfully by M. Pourcel of the Terre-Noire Works, for the production of sound steel castings, and is now very generally used with that object; but since silicon impairs the malleability and ductility of the metal besides necessitating greater care in the treatment of the metal under the hammer, it is not often used in the production of such mild steel as is used for structural purposes, and which requires to be hammered or rolled during its manufacture.

The silicon is introduced in the form of a *silico-ferromanganese*, containing about 10 per cent. of silicon, with 18 per cent. or upwards of manganese, and which, after heating to *redness*, is then added to the ladle containing the molten charge of Siemens' or Bessemer steel, immediately before the metal is run into the moulds. The addition is marked by a cessation of all ebullition and escape of gas through the covering slag, which was previously going on in the ladle. The silico-ferromanganese is added in such proportion that the steel shall contain from 0·2 per cent. to 0·3 per cent. of silicon, whilst to neutralize this high percentage of silicon, manganese to the extent of not less than 1½ times the amount of silicon should be present in the steel.

M. Pourcel considers that the action of silicon in preventing the unsoundness or honeycomb in steel-castings is due to the greater oxidability of silicon over carbon, whilst the oxide of silicon, that is, silica, is solid, and combines with manganous oxide to the production of a manganous silicate, which is liquid at the temperature of solidification of the steel, and so liquates from the metal. Müller questions this theory, and considers the effect of silicon to be due to the increased solvent action of silicon steel, whereby the gases, instead of separating, are kept in solution during the solidification of the metal, and thus more solid and homogeneous castings result.

219. Hadfield's Manganese Steel.—Mr. Hadfield claims, by the introduction of 10, 11, or 12 per cent. of manganese into cast-steel, to have produced thereby sound castings, and a metal which does not require either tempering, rolling, forging, or hardening after being cast, but which possesses at the same time a considerable degree of malleability and ductility. To prepare such steel, he melts in a suitable furnace a ferromanganese low in silicon and carbon, but containing 80 per cent. or upwards of manganese, and of this about 10 per cent. is added to the molten metal immediately before casting, which proportion yields a steel containing about 10 per cent. of manganese.

220. Applications of Pressure to Fluid Steel.—Of the methods employing external pressure for the consolidation of steel ingots, the ordinary procedure with small ingots, is to insert a cast-iron stopper on to the top of the metal in the ingot-mould, or to fill up the mould with sand, and then cover the sand with a plate, which is wedged down into firm contact with the metal. These are all methods for preventing the rising of the metal in the mould and the honeycomb *structure* produced thereby.

Sir Joseph Whitworth has succeeded in overcoming this difficulty of unsoundness in steel ingots, by submitting the metal, while in its fluid condition, to very considerable pressure; for this purpose the steel from the converter, furnace, or crucibles is run from the ladle into a steel mould lined with refractory material, and constructed so as to allow of the free escape of gas from the metal whilst being pressed. The metal is subjected to a pressure of several tons upon the square inch, by means of large hydraulic presses, specially constructed; such a press at the works of Sir J. Whitworth & Co., Manchester, being capable of exerting a total pressure of 8000 tons upon the fluid metal.

During the application of the pressure, jets of gas burn from a series of vents around the top and bottom of the mould, ejectments of metal also not unfrequently occur, and often a fine metallic rain passes through the sand lining of the mould, and escaping by the vents already mentioned, collects upon the top plate of the mould. From the beginning to the end of the process the ingot of steel shortens about 1½ inches for each foot of its length.

Steam at a pressure of from 80 *to* 150 *or* 200 *lbs.* has been applied by Mr. Jones of the United States to the consolidation of steel ingots. For this purpose a steam receiver is attached to the side of the crane, or in any other convenient position, and is connected by cocks and flexible copper tubes with the movable covers of the several moulds. Each mould is secured to a plate at its base by clamps, bolts, and lugs, or by pins and cotters, and each mould is also provided with a loose cover having a conical seat which fits into a corresponding conical seat prepared in the top of the mould. The cover having been removed, the metal is run into the mould through a runner box, which is quickly removed after the casting is completed, and the loose cover which is connected with the steam arrangement is inserted in position, and then wedged down so as to make the joint as tight as possible. Steam is then at once admitted, and the pressure is allowed to remain on for five minutes, or until the metal becomes solid. This process is, however, generally discarded owing to the small pressures available, the very imperfectly steam-tight joints that can be rapidly made, and the great cost for the moulds.

Carbonic anhydride has been used by Baron Krupp and others instead of steam. For this purpose Krupp proposes to have the carbonic anhydride (CO_2) in the fluid state, and to hold it in a reservoir which is heated or cooled as required according to the pressure to be exerted, since the pressure or tension of the carbonic anhydride increases very rapidly with the rise in its temperature. The moulds are of steel, and have a cover secured to the same by bolts and wedges, the joint being made gas-tight by an expanding copper ring placed between the mould and cover. There is a hole in the centre of the top-plate through which the metal is run into the mould, and which is closed by a sliding wedge after the metal has been cast and its surface covered over with sand or other bad-conducting material. Communication is then made between the reservoir of carbonic anhydride and the cover of the mould, and the pressure regulated as above is then applied.

Rapid *rotation of the metal* in the moulds is attended with good results for special forms of castings. For the purpose of rotation, the moulds are attached to a table, which, as soon as the casting has been made, is set into rotation at the rate of from 40 to 50 revolutions per minute.

A *Mechanical Stirrer* is proposed by Mr. Allen with the same object. The stirrer, which is suspended above the ladle, is lowered into the same, after the charge of molten steel has been tapped into it. The stirrer is then set into rotation, during which gases escape from the surface of the metal, and the ingots cast after such agitation are said to be more sound than when cast from the same metal without this agitation.

221. Steel-faced Armour.—For the purposes of armour, compound plates, formed of an outer face of comparatively hard steel, with a middle layer of mild steel, and an inner backing of soft malleable iron, all welded together so as to form one plate, have proved very successful for the purposes intended. The outer face of hard steel serves to resist penetration and the force of impact of the shot or shell, as also to break up the projectile, whilst the soft-iron backing prevents the hard steel from breaking up under the blow of the projectile. For the manufacture of such plates, a compound slab is formed, in which the proportions of the several thicknesses of *face*, *backing*, and *intermediate metal* to one another, vary according to the thickness of the finished plate, but generally the mild steel between the face and backing plates is made of about one-third the total thickness of the plate, if for heavy armour, and a little under this figure if thinner plates are to be produced.

In order to prepare a compound slab for the production of an 8-inch plate, the face plate of the slab is made of steel containing from 0·5 to 0·8 per cent. of carbon, and is of about 2 inches in thickness. The back plate is 12 inches in thickness, and is made of malleable iron containing about ·047 per cent. of carbon. These two plates are heated to redness, and placed on edge in the moulding box, sunk for the purpose in a pit in the ground. The front and back plates are separated by distance pieces at the ends, so as to leave a space between them of about 5 or 6 inches, whilst steel bolts pass through the plates so as to keep the whole together. The backing plate of the slab is placed against one side of the moulding-box, whilst the space between the other side of the moulding-box and the face of the front plate of the slab is filled in and rammed up with sand, as is also the space, being the ends of the moulding-box and the ends of the slab. A casting trough or runner box is placed along the length of the mould, over the space between the two plates, and from this several holes or gates deliver the fluid metal from the trough into the space between the iron and steel plates. Siemens' open-hearth steel is tapped as hot as possible from a ladle into the trough just mentioned, and the heat of the metal so introduced into the space between the front and back plates is sufficient to heat up the two plates, so that as soon as the compound slab thus formed has cooled down to redness, it may be lifted as one slab, and, after reheating, may be passed at once to the rolls to be rolled down to the required dimensions, after which treatment the union of the hard steel face, the middle of mild steel and the wrought-in backing plate, appears to be perfect.

When cold the compound plate is taken to the planing *machine*, where the ends and sides are parted off, and in *reducing* the plate to the finished dimensions, the end distance pieces and the steel bolts, etc., used in preparing the mould, are separated from the plate along with the other scrap.

222. Soft or Mild Centred Steel.—For certain purposes, as for the manufacture of taps, etc., where it is desired to make an article of a material, such that, while it may be hardened at the surface or working part, will yet retain the toughness due to the metal in its soft state, a variety of steel has been introduced, known as *mild centred steel,* in which the surface of the metal is much more highly carburized than the central part or core of the ingot or bar. In the manufacture of this class of steel, the ingots are cast of very mild steel in the manner already described; these ingots are then cogged (hammered) down, and afterwards introduced for conversion into the converting furnace (fig. 50, p. 214), where they are exposed for carburization, after the manner of ordinary bars in the converting process. In this manner the exterior of the ingot becomes carburized to a depth determined by the duration of the process, while the centre retains its original softness; and after again hammering or rolling to the sizes required, the steel is ready for use.

CHAPTER XI.

TIN.

This metal is of high antiquity, the Phœnicians, before the Christian era, having fetched the metal from the British Isles.

Tin is one of the whitest metals, possessed, however, of a peculiar faint yellowish tinge; it rivals silver in lustre, and when warmed emits a faint odour. A bar of the metal when bent produces a peculiar crackling sound, known as the *cry of tin*, supposed to be due to its crystals grinding over each other during the bending movement. Tin is one of the least tenacious of the metals, only lead and zinc being inferior to it in this respect, a wire 2 m.m. in diameter breaking under a load of 24 kilogrammes. It is very malleable; by hammering and heating, *tin-foil* can be obtained of not more than $\frac{1}{1000}$ of an inch in thickness; such *foil*, amalgamated with mercury, forms the silvering on the back of glass mirrors. Tin is easily obtained in crystals, behaving in this respect much like lead and bismuth. The appearance known as *moirée métallique* is formed by treating the surface of metallic tin with a mixture of ten parts of diluted sulphuric acid, with one part of diluted nitric acid, when the surface of the metal becomes covered with a mass of crystalline forms, giving this well-known ornamental appearance. The specific gravity of tin is 7·251, its linear dilatation from 0° C. to 100° C., is $\frac{1}{462}$ of its length. It melts at 230° C., and may be exposed to a strong heat in a *brasqued* crucible, without loss of weight. If heated in the air, it rapidly oxidizes to *stannic oxide* (SnO_2); melted at a low temperature, and poured out, it retains, if pure, its resplendent lustre for a considerable time, the brilliancy of the *surface* being one test of its purity; for, if impure, the surface will be more or less frosted, according to the amount of impurity present. It undergoes little change in dry or moist air (free from sulphuretted hydrogen) at ordinary temperatures, and is hence used for coating iron which is required to resist the action of moisture, the iron affording strength to the plate, while the coating of tin on its surface prevents the rusting away of the iron. Tin has a conductivity for heat less than half that possessed by silver; its surface takes a fine polish, when the radiation from it is also small; hence its value as a material for the manufacture of teapots, and other culinary utensils. It decomposes water at a red heat, is easily soluble in hot hydrochloric acid, with the evolution of hydrogen; boiling sulphuric acid acts violently on the metal, evolving sulphurous anhydride (SO_2), while the dilute acid acting in the cold, liberates hydrogen. Tin is soluble in the fixed alkalies, and diluted nitric acid acts violently upon it, liberating nitrous fumes, and converting the tin into metastannic acid. The chemical symbol of tin is Sn, and its atomic weight 118.

Tin reduces copper, lead, bismuth, and antimony when heated with their oxides. Commercial tin often contains minute quantities of lead, iron, copper, arsenic, antimony, bismuth, and tungsten; and less frequently manganese, zinc, and molybdenum.

The only compounds of tin with the non-metallic elements which are of metallurgical interest, are its combinations with sulphur and oxygen.

223. Stannous Sulphide.—Tin and sulphur combine readily on the application of heat; the resulting mass of stannous sulphide (SnS) generally contains, however, metallic tin. The product is not so fusible as tin, and is somewhat difficult to pulverise. Sulphide of tin, when roasted with access of air, is resolved into sulphurous anhydride (SO_2) and stannic oxide (SnO_2). The sulphides of tin, when heated with iron, suffer decomposition, the result being a compound of sulphur, iron, and tin.

224. Stannic Sulphide.—Stannic sulphide (SnS_2), or *mosaic gold*, is a scaly, micaceous, unctuous mass, somewhat resembling gold in appearance; a strong heat decomposes it into stannous sulphide (SnS) and free sulphur. This compound cannot be formed by the direct union of tin and sulphur, but is prepared by making an amalgam of two parts of tin with one part of mercury, triturating this amalgam with one part of sal-ammoniac (NH_4Cl) and one and a quarter of sulphur, then subjecting the mixture to a gentle heat (not too strongly), when the stannic sulphide remains at the bottom and around the sides of the vessel, in the form of gold-coloured spangles, and hence the name.

225. Putty Powder.—This substance is a crude peroxide of tin (SnO_2), used for giving an opaque whiteness to enamels, and for grinding glass, etc. It is prepared by heating metallic tin on the bed of a reverberatory furnace, and raking off the crude oxide or dross as it is formed; this dross is then subject to calcination, when it becomes whitish in appearance, and after grinding to powder constitutes what is known as "putty powder."

226. Ores of Tin.—*Tin-stone*, *cassiterite* or *stream-tin* (SnO_2) may be said to be the only ore of tin; it is black or brown in colour; the variety occurring in granite is usually more translucent, paler in colour, and much purer than that occurring in other rocks, the grey ores often containing a considerable amount of silica. Its specific gravity ranges from 6·3 to 7·1. As occurring in Cornwall, it is more or less mixed with a *gangue* of fluor-spar, wolfram, porphyry, granite, galena, blende, copper and arsenical pyrites, mispickel, chlorite, etc., and, in fact, specimens of nearly four-fifths of all the known minerals are found as associates of tin ores under different circumstances; tin ores require, accordingly, a series of careful and somewhat complicated *dressings*, including *stamping*, *picking*, and *washing* before being ready for the metallurgical treatment proper. When this mineral presents, on breaking, the appearance of a number of concentric layers, it is called *wood-tin*. Tin-stone occurs as grains or rounded detached masses in the old alluvial soils of Brittany, Saxony, Bohemia, East Indies, etc., in which form it is known as *stream-tin*. A mass of rock, containing only from ½ to 1 per cent. of tin-stone, may be profitably worked. Cornwall and Devon afford the largest deposits of tin-stone, but tin ores also occur in Malacca, the island of Banca, in Bolivia, and in smaller *quantities* in the Isle of Man, France, Spain, Russia, etc.

Tin pyrites, bell-metal ore or *stannous sulphide*, is brass yellow in colour, has a metallic lustre, and contains varying amounts of tin, copper, iron, zinc, and sulphur. No use is made of this ore for the extraction of tin.

The tin ores are carefully sorted by the stamping, picking, and washing processes into three qualities, according to their purity: the 1° quality is the purest and richest in tin, and is smelted separately for tin of the first quality; the 2° contains tin and other metals, and the 3° contains copper.

227. **Roasting.**—The ores of tin as they leave the mines still contain sulphur, iron, and arsenic, and are first roasted in large reverberatory furnaces (calciners) in charges of from 6 to 8 cwts. The charge is rabbled at intervals of from twenty to thirty minutes; and the temperature, especially at the commencement, is kept down so as not to agglutinate the sulphide of tin, otherwise the decomposition and oxidation ceases, and the mass requires re-grinding. The calcination is completed in from 12 hours to 18 hours, when the mass is drawn from the calciner, exposed to the atmosphere for a few days, and then transferred to a large tank containing water; the heavier portions containing the larger quantity of metal are collected at the bottom of the tank, and are sold to the smelter as *black tin.*

The result of the calcination or roasting has been to volatilize the arsenic as arsenious anhydride (As_2O_3), and to expel the sulphur largely as sulphurous anhydride, while the mass still retains cupric sulphate with ferric, stannic, and other oxides, of which the first mentioned is dissolved out in the lixiviation, while the ferric oxide, etc., is separated from the heavier stannic oxide by washing.

228. **Reduction.**—This operation involves two stages:—

1. *Smelting*, in which an impure tin is obtained, containing as its impurities chiefly iron and arsenic.
2. *Refining* of this impure tin.

The smelting of tin ore affords an example of a case of the simple reduction of a metallic oxide by carbon, with the conversion of the *veinstuff* or *gangue* into a fusible slag, but a high temperature is required to effect the decomposition.

The smelting of *black tin* is now usually performed in reverberatory furnaces, of which the roof is kept as low as possible, with a view to the economy of fuel. The furnace shown, fig. 63, has a fireplace A about 2 feet long, with the stack B at the opposite end of the bed; the fire-bridge E, about 14 inches in depth, is hollow, and without the usual cast-iron bridge plate, the fire being kept up above the bridge during the smelting operation; the bed C, about 18 feet in length and 9 feet across, is made shallow, and inclines from all parts towards the tap-hole D, at the opposite side to which are the doors G, through which the charge is rabbled. Below the tap-hole is the *float* H, a quadrangular or circular basin of sheet-iron lined with clay,

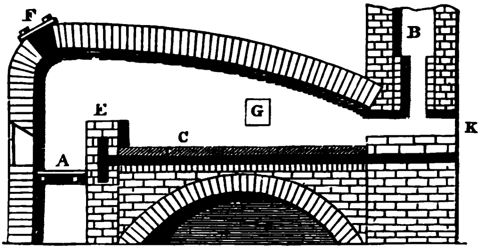


Fig. 63.—Vertical Section of the Reverberatory Furnace for Smelting Tin.

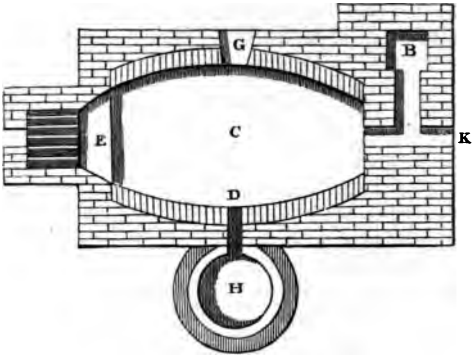


Fig. 64.—Plan of the Bed of the Reverberatory Furnace and Refining Kettle.

into which the metal is tapped from the furnace; on the right side of the *float* is placed a *kettle* of cast-iron, set over its own fireplace, and in this kettle the operation of refining is performed. The bottom of the furnace is formed of iron bars, which are laid transversely, and on these rests a bed of slate, above which is a bed of from 7 inches to 8 inches in thickness of fire-clay, and resting on this are fire-bricks built on end. A bottom thus prepared lasts about three months. Above the *refining kettle* or basin is placed a pulley, from which is suspended an apparatus by which billets of wood may be plunged to the bottom of the pot, and at the same time receive a rotary motion.

The charge of 24 cwt. of ore, yielding a produce of about 65 per cent. of metal, is mixed with one-fifth of its weight of anthracite, and is spread over the bed of the furnace; sometimes a little slaked lime or fluor-spar is also added to assist in the fusion of the gangue; the side doors are then luted up and the tap-hole is stopped with clay. The heat is now gradually raised; for if raised too rapidly a loss occurs from the formation of stannous silicate, which escapes reduction. In about five hours after charging the mass is well rabbled, and a quantity of *culm* (anthracite) is thrown into the furnace; the mass is again rabbled after a lapse of about forty-five minutes, and the metal is ready for tapping after a further interval of fifteen minutes. After tapping, a scoriaceous mass remains on the furnace bottom, containing shots of metal and particles of anthracite; this is raked out through the end door K, and forms what the smelter calls *slag*, though the true fused slag, called by him *glass*, runs out of the furnace with the metal on tapping. The glass is essentially a ferrous silicate, and when solidified is removed from the top of the metal in the pot or float, and put aside; the scum on the surface of the metal is also skimmed off. For working off this charge of ore about 15 cwt. of coal is required as fuel, and 5 cwt. of anthracite for the reduction of the metal. The slags produced in this smelting, and which are again smelted for tin when the furnaces are not busy, are essentially ferrous and aluminous silicates, with small proportions of the oxides of tungsten, magnesium, calcium, and manganese, but always containing a *considerable proportion* of tin; in some cases, as in the following specimen, as much as 21 per cent. of tin occurs in the slag.

GLASS OBTAINED IN SMELTING TIN.

Silica,	36·77
Blue oxide of tungsten,	4·93
Stannous oxide,	23·87
Ferrous oxide,	19·30
Manganous oxide,	0·47
Alumina,	11·71
Lime,	1·83
Magnesia,	0·66
	99·54

229. **Refining.**—The whole of the tin for commerce is subjected to the refining operation, although we see quoted *common*, *refined* and *grain tin*, the difference being that the refined tin is made from the best ores and boiled longer in the refining operation than is common tin; while, for the production of *grain tin*, the finest pigs are heated just below their melting point, and allowed to fall from a considerable height, when the metal breaks in the form of long grains.

Before the refining proper, the tin undergoes a process of *liquation*, that is, the pigs of tin are placed upon the bed of a reverberatory furnace similar to the last, except that the bed is made to slope rather more. About 18 tons of pigs are placed in the furnace and arranged near the bridge; the temperature is raised and carefully regulated so as to be only sufficient to melt the tin without wholly melting the pigs, the tin then flows or liquates continuously away into the kettle, leaving on the furnace bottom a somewhat refractory and very hard mass, known as *hard-head*, into the composition of which enters about 50 per cent. of iron, 20 per cent. of tin, 20 per cent. of arsenic, 2 to 3 per cent. of sulphur, and a trace of copper. As the tin liquates or runs away, more pigs are added until the kettle has received its full charge. When the kettle, which is about 4 feet 6 inches in diameter, and heated by its own fire, contains about 7 tons of metal, billets of *green wood* (by preference the apple tree) are introduced and kept depressed, by the appliance previously mentioned, below the surface of the melted metal. The gases disengaged from the wood cause the tin to boil up, and a skum consisting chiefly of iron, tin, and arsenic, or the same as that left on the furnace bottom after liquation, forms on the surface, and is skimmed off from time to time. The refining is from one hour to eight hours in duration, according to the amount of impurities present, and also whether common or refined tin is the object of the operation, but the average time is from two to three hours.

For *common tin*, the metal is ladled from the kettle into the moulds while the wood is still maintained beneath the surface, and fresh metal continues to run in from the furnace; but for *refined tin*, besides being made from the purer ores, the refining is continued longer, the wood is withdrawn, and the metal allowed to separate into layers before lading is commenced; the upper strata or layers, being the purer, are set aside for *grain tin*, the middle as *common tin*, while the lower are still so impure as to require again liquating. The moulds into which the tin is ladled are usually made of granite, and the product is sold as *block tin*.

Instead of the *boiling* or *poling* just described, a process of *tossing* is sometimes followed, that is, the melted tin is raised in ladles and allowed to fall for several feet through the atmosphere into the refining vessel, thus exposing a large surface to the cooling influence of the air, whereby the less fusible metal, *hard-head*, containing the impurities of the tin, separates and floats on the surface as a skum, which is removed while the purer tin liquates out. The scum or *hard-head* produced in this operation, has a similar composition to that left on the furnace bottom in the furnace liquation described.

If specimens of the metal, ladled into small stone ingot moulds, retain their bright clear surface with full rounded sides until cold, the metal may be classed as *refined* or *grain tin;* but if the metal, though bright when hot, acquires a frosted appearance at the moment of solidification, and is also not so round and full at the sides, it is classed as *common tin;* and should the metal have a yellowish tinge, and exhibit striae or a frosted appearance before solidification, it requires further liquation and refining.

In Germany, tin is still smelted in the blast furnace with charcoal as the fuel, and in this manner much of the purer tin, known as *grain tin*, is still produced; but the loss of metal and consumption of fuel are much greater than in the reverberatory furnace, and hence its use has been altogether discontinued in England. The tin smelted in blast furnaces with charcoal as fuel, is reported, however, to be purer than when the reverberatory furnace is employed.

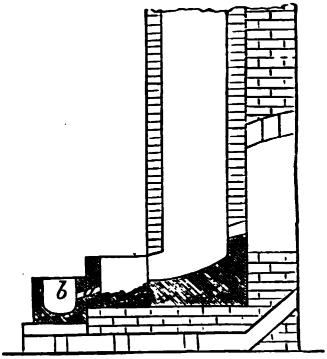


Fig. 65. — BLAST FURNACE FOR THE SMELTING OF TIN.

The furnace employed at Altenberg is a low blast furnace, built of large blocks of granite or porphyry, surmounted above by a hood, the blast being supplied by bellows; the ore, with reducing agent and flux, is introduced at the top, and in about four hours the metal begins to run from the tap-hole, the furnace being kept filled with smelting materials while the smelting operation continues. As the smelting proceeds, the metal and slag run out together along a channel provided for the purpose, and collect into a basin, from which, as it fills, the slag which floats on the surface is passed down an incline *a* into another receptacle *b* full of water; after which treatment the slag is easily broken up for subsequent re-smelting, the metal being tapped as the basin fills into another vessel at the opposite side to that which receives the slag.

230. Oxland's Process.—Wolfram, a tungstate of iron and manganese frequently present in tin ores, cannot be separated from the tin-stone by any mechanical treatment, by roasting operations, or by treatment with acids; and should it be present in considerable quantity, it renders the tin difficult to fuse during its reduction. The process patented by Mr. Oxland has for its object the removal of the wolfram from tin ores, by converting it into a soluble tungstate of soda, which can then be dissolved out by lixiviation. For this purpose the ore is treated with carbonate or sulphate of soda, in a reverberatory furnace of special construction; the hearth of the furnace being formed by an iron pan, arranged so that the flame from the fireplace, after passing over the pan or hearth, is directed backwards beneath the pan to the chimney. By the use of an iron pan, instead of a brick or other siliceous bottom, the formation of silicates of tin is prevented. The charge of from 6 to 9 cwt. of ore is placed on the bed of the furnace, and from 9 to 12 cwt. of carbonate of soda or crude soda is spread over the heated ore. The mass is stirred or rabbled every fifteen minutes, and a quantity of coal is thrown to the back of the hearth about every half hour. In about six hours the operation is completed, when the pasty mass is drawn from the furnace, allowed to cool, and then broken up in the stamping mill into pieces of the size of an egg; to facilitate this disintegration, about 25 per cent. of quartz is added, which in the mill serves to break the hard alkaline crust which has formed around the pieces of tin ore. The mass is now repeatedly washed, and the coarser portions are restamped; while sometimes a second fusion with carbonate of soda is necessary.

If sulphate of soda be used instead of the carbonate, the loss of tin from the formation of stannates of soda is not so great, but the management of the process is more difficult, requiring greater care for the maintenance of the proper condition of the flame. The charge of ore, sulphate of soda, or salt cake and small coal, is heated in a reverberatory furnace, a reducing flame being maintained until the sulphate of soda is reduced to sulphide of sodium, when a bright oxidizing flame is required to effect the decomposition of the sulphide, with the formation of tungstate of soda; after six hours the charge is drawn and thrown into a cistern of water, when the tungstate of soda is dissolved as before.

231. Tin and Iron.—These two metals have a great affinity for each other; in tin plates, at the junction of the tin and iron, there exists a true alloy of the two metals. Tin containing 2 per cent. of iron is magnetic, hard, and sensibly duller in lustre than pure tin. Cast-iron alloyed with about 5 per cent. of tin is hard, and exhibits a steely fracture; and 0·5 per cent. of tin in malleable iron renders it hard and unworkable under the hammer in the cold state. When an alloy of iron and tin containing an excess of the latter is heated continuously, a portion of the tin will liquate from the alloy, and there remains behind a more or less infusible alloy of iron and tin, corresponding to the *hard-head* already mentioned under the refining of tin. An alloy of 80 parts of tin with 10 parts of iron has been proposed instead of pure tin for the tinning of copper utensils.

232. Tin Plates.—What are known as tin plates in commerce are thin plates of iron or steel, coated or alloyed on their surface with metallic tin. In such plates the iron gives strength to the plate, while the tin prevents the rust or oxidation of the surface, which takes place when iron plates are exposed unprotected to the action of air and moisture. For the manufacture of tin plates, and especially for the better qualities, the iron is subjected to a special refining, in which the fuel employed is entirely charcoal, and the plates produced are known as *charcoal plates*, whilst the inferior variety of tin plates, known in the market as *coke plates* or *cokes*, are made from puddled iron. The manufacture of the iron plates required for the production of tin plates has been noticed under iron, and the treatment of the bars after leaving the refinery will only be described in this place.

The bars of refined iron (tin-plate bars) are cut to the proper length for the size of plates to be produced, when the bars so obtained are heated to dull redness, and passed several times through a pair of narrow rolls; the plate thus produced is doubled upon itself, and a little coal dust is introduced between the surfaces to prevent their adhering together. The ragged edges produced by the previous rolling are cut off, and, after reheating, the double plate is again rolled; this operation of doubling over, reheating, and re-rolling, is repeated, until the plate has acquired the necessary thinness, and the final plate consisting of 4, 8, 12, 16, or 32 thicknesses, leaves the rolls as though it were one plate; but the heat has been so regulated as to prevent the plates welding together during the rolling, except in odd and accidental cases. The several folds of the plate are now separated, and the plates are cut to the proper dimensions. Before the *black plates* thus obtained can take the coating of tin effectually, it is necessary to clean the surface of the plate from all adhering oxide or scale formed during the heating and rolling processes, and for this purpose they pass to the *pickling* room. The *black plates* for the purposes of pickling are placed on edge upon a suitable carriage or cradle, so as to leave a space between each plate for the circulation of the pickling liquid between them. The cradle is suspended from one arm of a kind of crane, and the whole is dipped or immersed in warm dilute sulphuric acid, each cradle holding about one ton of plates at a charge. After agitating the plates for some time in this bath, known as the *black pickle*, the cradle and its charge of plates are withdrawn, another charge having, in the interval, been prepared for dipping into the same bath, and in this manner the bath is kept in constant operation. The plates of the charges just withdrawn from the pickle are unpacked, and either scoured with sand under water, or are simply washed or swilled in clean water, so as to clear them from acid and any loose scale. Instead of lowering a carriage into the pickle, as above, by a dipping crane, an arrangement of bath, with a series of endless chains working in the same, is adopted in some works. In this case the workman, at one end of the chains, places the plates singly upon the chains as they travel. The plates are thus carried through the bath to the other end, where they are received by another workman, who swills or rinses them in clean water in a cross channel across the head of the pickling bath. Instead of using dilute sulphuric acid, in some works the black pickle is made of crude hydrochloric acid in the proportion of 8 lbs. of acid to about 6 gallons of water. The plates after pickling require *annealing*, for which purpose they are packed into a cast-iron box about two feet square, from which the air is carefully excluded by luting on the cover. Several of these boxes are placed together in a kind of reverberatory furnace, where they are maintained for about twelve hours at a cherry-red heat, just insufficient to make the plates adhere together, when, after cooling, the plates are *cold* rolled, which gives to them a smooth and somewhat lustrous appearance. After again annealing, the plates are subjected to a second pickling, in the so-called *white pickle*, but the duration of the immersion is shorter than in the previous pickling. The white pickle, like the first bath, is also composed of dilute sulphuric acid, and an arrangement similar to the last is adopted for inserting the annealed plates into the bath. The plates on withdrawal from this pickle present a white frosted appearance, and are then ready for the *tinning* operation.

The tinning apparatus consists of a range of six pots placed over suitable fires, and called respectively the tinman's pot, tin-pot, washing-pot (divided into two compartments), grease-pot, cold-pot, and the list-pot. The plates are first immersed in the melted grease of the tinman's pot, until all moisture is evaporated from their surfaces; from here they are introduced into the melted tin, contained in the tin-pot, the surface of which is covered by a layer of grease; the coating or tinning is not completely effected here, and the plates are transferred to the first division of the wash-pot, also containing melted tin, where the plates remain until the coating is perfect, and the excess of tin has run from the surface, to complete which the workman takes each plate and wipes both sides of it with a brush of hemp; to remove the streaks left by the hemp, the plate is then quickly dipped into the second division of the wash-pot, containing the purest melted tin; from whence the plates are removed to the grease-pot containing melted grease, maintained at a heat regulated so as to allow the excess of tin to run off, and also to cool the plate uniformly, and prevent any unequal contraction of the iron plate and the tin on its surface. After ten minutes immersion in the grease-pot, the plates are inserted in the melted tallow contained in the cold-pot. To remove the bead or thick wire-edge of tin, which has drained down and collected at the lower edge of the plate, it is inserted into the list-pot, which contains a depth of about ¼ inch of melted tin at a moderately high temperature, whereby the wire of tin is melted, and then by striking the plate sharply with a stick the metal is detached. The plates now only require rubbing with bran to clean them from grease and dirt, and afterwards with a sheep-skin, when they are ready for the market.

Instead of simply dipping the plates into the molten tin, and then draining the same in the manner above described, in many of the South Wales works a pair of finely finished rolls revolve within the bath of molten tin contained in the wash-pot, and between these rollers the plates pass as they leave the bath, whereby any superfluous tin is removed and saved. By the use of these rollers also, the formation of any rim or list of tin upon the lower edge of the plates is prevented, and the list-pot therefore becomes unnecessary.

233. **Terne Plate** is the name applied to an inferior variety of tin plate, in which the iron is coated with an alloy of about two-thirds lead and one-third of tin, instead of with pure tin.

234. **Bronze.**—The composition of bronze varies considerably, ranging from 75 to 95 per cent. of copper, with from 25 to 5 per cent. of tin; the ancient bronze consisted of 90 per cent. of copper and 10 per cent. of tin, figures representing the composition of what is now known as *gun-metal*, the use of which for ordnance, except for guns in India, has been discontinued. The bronze coinage consists of 95 per cent. of copper, 4 per cent. of tin, with 1 per cent. of zinc; the old bronze of statues, etc., contains zinc, and frequently lead, the zinc being said to prevent the formation of cracks or fissures in castings of bronze, which would otherwise appear.

Bronze is of a yellowish-grey colour, and if cooled slowly, is very sonorous, brittle, and hard; but if heated to redness, and cooled quickly, as by immersion in water, it is rendered soft and workable, in this respect behaving in an exactly opposite manner to steel under the same treatment. It is very tough, is hardened by hammering, and is malleable at a temperature a little below redness. Bronze is not readily affected by exposure to the atmosphere, but on long continued exposure, its surface becomes coated with a film of carbonate of copper, suboxide of copper, and Dr. Percy has detected crystals of stannic oxide. Its specific gravity is greater than the mean of its constituents, and it is more fusible than copper.

The preparation of bronze requires considerable care, since, owing to the very wide difference in the melting points of copper and tin, the latter has a tendency to separate, and the alloy to form into strata of very varying composition. The manufacture of bronze consists of two stages: 1° The tin is melted in crucibles and alloyed with its own weight of copper, the resulting alloy being known as the *white alloy* or *hard metal;* and 2° the various bronzes are then made from this white alloy by melting the copper separately, and, while melted, adding it to the white alloy in amount necessary for the production of the required bronze. For casting large guns or other large articles, or masses requiring great care, the alloy is melted in reverberatory furnaces of special construction, with round or oval hearths, wood being employed as the fuel. When the copper, or copper and old bronze, has been placed on the bed of the furnace, the heat is raised rapidly. The tin, as being the most affected by oxidation, is not inserted until the copper is completely melted; but when the copper is melted the tin is charged into the furnace and pushed to the bottom of the bath of molten copper, the surface of the fluid metals being covered with charcoal, and access of air to the hearth prevented as thoroughly as possible. The tin is introduced in the form of small pigs which facilitates its fusion, and the mass is continually stirred or poled with a pole of birchwood, so as to keep the alloy as liquid and homogeneous as possible; and any scum which rises to the surface is removed as it forms. In making bronze for statues or other objects, where strength and definite composition are not material, rough old copper, with adhering solder, etc., are frequently used, and hence the introduction of many impurities into bronze of this class.

235. Bell Metal.—This is an alloy of copper and tin, containing usually from 70 to 80 per cent. of copper; but it is usual to call all alloys with from four to two parts of copper to one of tin as "*bell-metal.*" The bell at Westminster (Big Ben) was specified in the contract to consist of 76 per cent. of copper and 24 per cent. of tin. Antimony is occasionally found in bells, especially in the older specimens.

236. Speculum Metal.—This is a very hard, brittle, steel-grey alloy, capable of receiving a very uniform and highly polished surface; it contains about 30 per cent. of tin, or about two parts of copper to one part of tin; from 2 to 3 per cent. of arsenic is also sometimes added for the purpose of hardening it, and rendering it more susceptible of a high polish. Its composition on cooling, after fusion, remains more uniform than the previous alloys of copper and tin.

237. Pewter.—Pewter is a very malleable alloy of lead and tin, of very variable composition. The common variety is composed of 80 parts of tin to 20 of lead; while for plates, teapots, etc., the alloy is void of lead, but contains 89 per cent. of tin, 7 per cent. of antimony, with 2 per cent. of copper and 2 per cent. of bismuth.

238. Britannia Metal.—This is an alloy of tin, antimony, bismuth, copper, and zinc, in very variable proportions, which is highly malleable, and can be rolled out and spun into various shapes. In its preparation equal parts of plate brass, bismuth, antimony, and tin, are melted together, and the resulting alloy added to melted tin, until the proper colour and hardness for its desired use is obtained: that for spinning contains about 94 parts of tin, 5 of antimony, and 1 of copper; while for rolling the proportions of 90 parts of tin, 7 of antimony, and 3 of copper are added; while the metal for casting teapots, etc., in hollow moulds, consists of about 84 parts of tin, 10 of antimony, 4 of copper, and 2 of bismuth.

239. Tin and Zinc.—These alloy well together on fusion; the zinc increases the hardness, but lessens the ductility of the alloy.

240. Amalgam, etc.—The amalgam used for the rubbers of electrical machines, consists of 25 parts of tin, with 25 of zinc, and 50 of mercury. Gold forms a malleable alloy with pure tin, whose specific gravity is above the mean of its constituents; with silver, also, a white malleable and readily oxidizable alloy may be obtained.

241. Tin and Lead.—These metals alloy well together in all proportions, the metals not separating on cooling after fusion, as occurs when the lead is replaced by copper. Pewter, already mentioned, and *plumber's solder*, are alloys of this class; the hardness and tenacity of these alloys are at a maximum when the metals are present in the proportion of three of tin to one of lead. Plumber's solder varies in composition, containing from 30 to 60 per cent. of tin, the remainder being lead. *Type metal* is an alloy of equal parts of antimony and tin, with two of lead. Fusible alloy is a body which melts at 200° F., or below the temperature of boiling water, and is accordingly used for plugs and other purposes, where the temperature is required not to exceed this limit; it consists of eight parts of bismuth, four of lead, and four of tin; the addition of a little cadmium to this alloy constitutes *Wood's alloy*, which fuses at 145°F. or 63°C.

242. Tinned Pins.—Brass pins are coated with tin, by boiling them with cream of tartar, common salt, alum, granulated tin, and water; the action is partly chemical and partly electrical, the zinc of the brass separating the more electro-negative metal tin from its solution, and depositing it on the surface of the pins.

243. Tinning of Copper.—The operation of tinning copper utensils or copper plates is very readily effected. For this purpose the surface of the copper plate is first rendered smooth by rubbing it with a fine sandstone, after which the plate is heated and its surface is rubbed over with salammoniac (NH_4Cl), the effect of which is to remove any oxide of copper from the surface of the plate, and to leave it perfectly clean and bright; a small quantity of tin, or tin alloyed with lead, along with a little powdered resin, is now placed upon the copper, and the plate is again heated, when the resin is the first to melt, and coats the plate with a coating which prevents oxidation from the contact of the heated plate with the atmosphere, when, as the tin melts, it is spread with a piece of tow over the surface of the copper, to which it becomes perfectly united.

CHAPTER XII.

ANTIMONY.

244. Properties.—Antimony is a bluish-white, very brittle metal, which crystallizes in the rhombohedral system, giving rise to the stellate or fern-like markings occurring on the surface of the metal as cast in the form of cakes; its density is about 6·8; it fuses at a temperature near 430°C., and is slowly volatilized at a white heat in an atmosphere of hydrogen; it is not sensibly altered by exposure to the atmosphere at ordinary temperatures, but at a red heat it burns with a bluish-white flame, with the production of thick white fumes of antimonious oxide (Sb_2O_3). Heated with strong sulphuric acid, sulphate of antimony is produced with the evolution of sulphurous anhydride (SO_2), while the dilute acid is without action upon the metal. It is rapidly oxidized without solution upon treatment with nitric acid, the degree of oxidation depending upon the concentration of the acid. Powdered antimony is attacked by boiling hydrochloric acid with the evolution of hydrogen, but in the massive state it is not affected by the treatment. Antimony and sulphur readily combine under the influence of heat. The chemical symbol of antimony is Sb, and its atomic weight is 122.

245. Impurities in the Metal.—The most frequent impurities occurring in *commercial antimony*, are sulphur, potassium, sodium, arsenic, lead, bismuth, iron, tin, silver, and traces of copper, the presence of small quantities of tin rendering the metal more largely crystalline. It may be freed from sulphur, arsenic, iron, and copper (but not lead), by fusing for an hour, in a Hessian crucible, a mixture of coarsely pounded antimony with $\frac{1}{8}$ of its weight of sodic carbonate and $\frac{1}{16}$ of its weight of grey sulphide of antimony, when the iron and copper are converted into sulphides, which in combination with sodium sulphide passes into the slag, while the arsenic passes out as sodic arsenate. After cooling and separation of the slag, the metal may be again fused with sodic carbonate for the further elimination of arsenic. The arsenic cannot be removed in this manner until the whole of the iron has been separated from the alloy.

246. Oxides of Antimony.—As already stated, if antimony be heated in the atmosphere to a sufficiently high temperature it burns, producing white fumes of *antimonious oxide*, or *flowers of antimony* (Sb_2O_3); the same oxide is produced when steam is passed over strongly-heated antimony. Thus—

$$2Sb + 3OH_2 = Sb_2O_3 + 6H.$$

This oxide is a white powder, fusible and volatile at a red heat, subliming without change if heated out of contact with the air, but passing to a higher state of oxidation if kept fused with contact of the air; it is soluble in tartaric acid, yielding *tartar emetic*, and on treatment with nitric acid or potassic chlorate, it is converted into a higher oxide. Antimonious oxide is reduced to the metallic state when heated to a red heat with carbon, or if carbonic oxide or hydrogen be passed over the heated oxide; it is also reduced by heating with cyanide of potassium; and zinc, tin, or iron precipitate the whole of the antimony from solutions of this oxide. When an antimony salt is treated with zinc and a dilute acid, a portion of the liberated hydrogen escapes in combination with antimony as antimoniuretted hydrogen (SbH_3), which is decomposed, like the corresponding arsenic compound, at a red heat with the deposition of metallic antimony.

The *tetroxide of antimony* (Sb_2O_4) occurs native as *cervantite* or *antimony-ochre*, and it is formed when antimony or antimonious sulphide (Sb_2S_3) is heated in the atmosphere, or by the action of heat upon antimonic oxide (Sb_2O_5), when it forms a powder which is yellow while hot, but white when cold. This oxide is reduced by carbon, but in this case the addition of a little carbonate of soda is necessary in order to collect the metal.

The highest oxide of antimony is *antimonic* oxide or anhydride (Sb_2O_5), which at a red heat is resolved into the last-mentioned oxide and free oxygen. The pigment known as *Naples yellow* is an antimoniate of lead.

247. Sulphides of Antimony.—There are two sulphides corresponding to the two principal oxides of antimony; but the *antimonious sulphide* (Sb_2S_3) is the only one of metallurgical interest; it occurs native as the minerals *stibnite* or *grey antimony ore*, *antimony glance*, etc., or it may be prepared artificially by melting sulphur with antimonious oxide, when sulphurous anhydride escapes, and antimonious sulphide is left, on cooling, as a crystalline mass.

$$2Sb_2O_3 + 9S = 2Sb_2S_3 + 3SO_2.$$

By roasting this sulphide at a temperature below its fusing point, sulphurous anhydride is evolved, and antimonious with antimonic oxide remain. It is decomposed by carbon at a high temperature, with the evolution of sulphide of carbon and separation of metallic antimony; it also suffers decomposition at a red heat when in contact with *tin*, *iron*, *copper*, *potassium*, or *sodium*, with potassic cyanide (KCy), or with a mixture of carbonate of potassium or sodium with charcoal, the resulting sulphide combining with the excess of antimonious sulphide; or if the reducing metal be in excess, it occasionally alloys itself with the reduced antimony. Steam passed over antimonious sulphide liberates sulphuretted hydrogen (SH_2), and an orange-yellow body sublimes, containing antimonious oxide and sulphide. A violent reaction ensues when antimonious sulphide is fused with nitre; the sulphur and antimony being oxidized with the formation (if the nitre be in excess) of sulphuric acid and antimonic oxide. Antimonious sulphide is decomposed by hydrochloric and nitric acids.

248. Antimony Glass.—This is an artificial oxysulphide of antimony, varying in colour from a yellowish-red to a hyacinth-red; it is prepared by converting the grey sulphide of antimony into oxide by roasting it at a moderate heat, then fusing this product, known as *antimony ash*, in an earthen crucible with about $\frac{1}{20}$ of its weight of sulphur.

249. Livers of Antimony.—This is a black or brown-black crystalline potassium sulphantimonite, prepared by fusing antimonious sulphide (Sb_2S_3) with potassium sulphate and charcoal, or by melting the sulphide with an alkaline carbonate, sulphur, and charcoal.

250. Ores.—Antimony occurs *native*, alloyed with arsenic, nickel, silver, and iron; in combination with oxygen as *antimony bloom* or *valentinite*, and as *antimony ochre* or *cervantite;* but the chief ore, and that from which the antimony of commerce is extracted, is *stibnite* or *grey antimony ore*, the sulphide of antimony (Sb_2S_3), which often contains also copper, iron, and arsenic; this ore occurs associated with gneiss, quartz, clay-slate, mica-slate, limestone, heavy-spar, etc., in Borneo, Hungary, Germany, Bohemia, France, Cornwall, and the United States. Sulphide of antimony, along with sulphide of silver, occurs in *ruby silver;* and *red antimony* is a mixture of the oxide and sulphide of antimony occurring in Tuscany. Antimony likewise occurs frequently as a constituent of numerous other minerals, and ores of other metals, particularly with lead and silver, as in Jamesonite, Bournonite, and Miargyrite, and with copper in antimonial copper, etc., but these cannot be considered as ores of antimony.

251. Reduction.—The *crude* antimony of commerce is merely the sulphide, freed by a process of *liquation* from the gangue or vein stuff accompanying the ore, and for this purpose the ore in not too small pieces is heated, either in conical pots, perforated at the bottom and having a receiver beneath each of them, or on the inclined bed of a reverberatory furnace, the liquated sulphide of antimony being conveyed along channels in the bed to a receiver outside the furnace. In either case the temperature must not be too high, but requires careful regulation, otherwise the sulphide of antimony softens and forms a pasty mass with the gangue of the ore, from which the antimony cannot be readily liquated. The pots first mentioned may be heated in a reverberatory furnace with the receivers placed beneath the hearth, or in a furnace (fig. 66) as used at Malbose in France, and known as "Penserat's Furnace," in which the cylinders or pots *a*, *a*, perforated at the bottom, stand on plates similarly perforated, and beneath each of which is a small oblong chamber containing the cast-iron receiving pots b, b, lined with clay; four of these cylinders are arranged in one furnace, with the fire-bars from back to front on each side of, and between the pots; the charge of the cylinders is introduced from the top, the furnace being surmounted by the hood *d*, with openings, as shown, for gaining access to the tops of the cylinders. A charge of 5 cwt. of ore is introduced into each of the cylinders, and wood fires are first made on the grates, but a little coal is subsequently supplied to the fire; and the sulphide or crude antimony melts and *liquates* out from the charge into the receivers beneath. The operation is completed in about three hours, with the production of about 2½ cwts. of a *crude* antimony, which contains from 60 to 70 per cent. of metallic antimony, with lead in variable proportions up to 10 per cent., a little iron, traces of arsenic, and from 25 to 30 per cent. of sulphur.

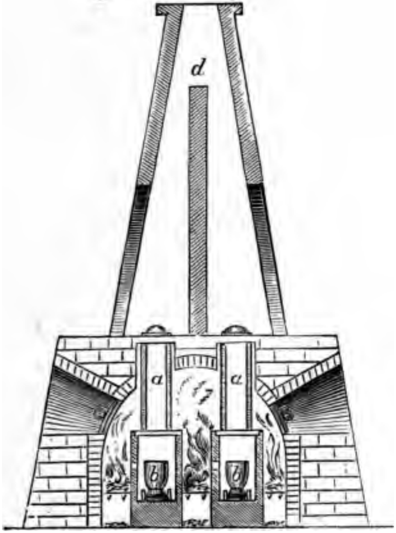


Fig. 66.—PENSERAT'S FURNACE FOR THE SMELTING OF ANTIMONY.

In France, in the department of Ardèche, where fuel is cheap and abundant, the pots, instead of being placed in a furnace, are arranged in rows of twenty-five or thirty each, between *two walls* about 9 inches in height, each pot stand-*ing upon a receiver* sunk in the ground, the space between the pots being filled with fuel. A construction of this kind works off a melt or charge in about ten hours, and four melts suffice to fill each receiver with the crude metal.

To separate the *metallic* antimony from the *crude* antimony obtained in these processes, the crude antimony is heated to bright redness, in covered crucibles, along with iron filings, nails, or small scrap-iron, such as the clippings of tin plates, etc. These crucibles are heated in reverberatory furnaces, being careful that the antimonious sulphide in the charge is always in excess, since any excess of iron is alloyed with the reduced antimony. A very gentle heat suffices to effect the decomposition, but a somewhat higher temperature is required to collect the metallic antimony into a distinct stratum in the crucible; the decomposition is formulated in the following equation :—

$$Sb_2S_3 + 3Fe = 3FeS + 2Sb.$$

It is further necessary to fuse this product with sodic carbonate, nitre, or borax, or these substances along with a little charcoal, whereby a readily fusible double sulphide of iron and potassium or sodium is formed, while the antimony separates readily. For the separation of the last traces of sulphur, arsenic, iron, and copper, the product is subjected to a second or third fusion with carbonate of soda, antimonious oxide or potashes (crude carbonate of potash), when the metal is cast into large circular moulds with rounded bottoms, in which it is allowed to cool under a layer of a very fusible slag, or under a stratum of melted tallow, when the surface of the cake should present the appearance of fern-leaf crystals.

Instead of the above methods of *reduction by iron*, the metal may be reduced from its sulphide by roasting in a reverberatory furnace at a dull red heat, and fusing the roasted ore with charcoal and an alkaline flux. In the roasting, sulphur and arsenic are expelled as sulphurous anhydride (SO_2), and arsenious anhydride (As_2O_3) respectively, which are accompanied with a little antimonious oxide (Sb_2O_3), the two latter condensing in the flues; and there remains a reddish-brown residue of the mixed sulphide and oxide of antimony, which is reduced to powder and mixed with about $\frac{1}{5}$ of its weight of charcoal, and the like amount of carbonate of soda, sodic chloride, or sulphate of soda, and slags from a previous operation, or with a mixture of coal and potassic carbonate; this mixture is then heated upon the bed of a reverberatory furnace or in crucibles, when the metal known then as "REGULUS OF ANTIMONY" separates beneath a layer of slag or flux, consisting of the sulphides of antimony and sodium or potassium, the slag so obtained constituting the product known in commerce as "CROCUS OF ANTIMONY." The metal prepared in this manner is purified, as in the "iron reduction process," by fusion with nitre.

In England, when smelting rich ores, the "regulus of antimony" is separated *direct* from the ore (without the preliminary liquation first described) by introducing the broken ore into red-hot crucibles, and placing upon the charge so introduced a layer of an alkaline flux, and lastly scrap-iron is pressed down upon the mass; upon melting, the iron is mixed with the mass, and in from two to two and a half hours the reduction is complete, and the contents of the crucibles are poured into moulds, the metal collecting as the lowest stratum, above which is a layer of ferrous sulphide, and on the top an alkaline slag.

252. Alloys.—The effect of antimony is to harden the metals with which it is alloyed, and generally to *impair* the malleability and ductility of the malleable metals. Antimony is alloyed with the softer metals, as lead and tin, to harden them; *stereotype* metal, an alloy of this class, consists of lead with about $\frac{1}{6}$ of its weight of antimony, and a small proportion of tin. Alloyed with tin, and occasionally bismuth, it constitutes the varieties of Britannia metal and Pewter, as described under alloys of tin; and an alloy consisting of 80 parts of tin with 20 of antimony constitutes the metal employed for music plates; while an inferior kind of Britannia metal, known as "Queen's Metal" is an alloy formed of 75 parts of tin, with 8·5 of antimony, 8 of bismuth, and 8·5 of lead. Copper and antimony alloy well together, producing a crystalline violet body, of no use in the arts, 0·15 per cent. of antimony in copper rendering the latter both hot and cold short. The presence of 0·5 per cent. of antimony in fine gold renders it quite brittle, and even ·05 per cent. of this metal injures its malleability. The presence of 0·1 per cent. to 0·3 per cent. of antimony in malleable iron makes it *both hot* and cold short. Lead containing antimony is notably hard, but there is little, if any, commercial lead absolutely free from this impurity. The operation of softening lead, described when treating of that metal, has for its object the removal of the antimony by the joint action of heat and air upon the alloy, the more ready oxidizability of the antimony permitting of its removal by simple heating of the alloy in contact with air, when a scum rises to the surface consisting largely of oxide of antimony and antimoniate of lead, with a small proportion of oxide of lead and some metallic lead. An alloy of antimony, lead, and mercury is harder than lead, while retaining its ductility; an alloy of this kind has been patented for use as ships' sheathing, to prevent fouling of the bottoms.

CHAPTER XIII.

ARSENIC.

Arsenic is an element of a steel-grey colour, with a metallic lustre, crystallizing in rhombohedra, and has a specific gravity in the solid state of from 5·62 to 5·96; it has never been seen in the fluid state, volatilizing at a dull red heat without previous fusion, evolving at the same time a powerful odour resembling that of garlic; its behaviour on exposure to the air depends much on the temperature employed in, and the mode of, its preparation; if the metal be obtained as a dark-grey crystalline powder, such as forms in the cooler parts of the condensing apparatus employed in its sublimation, or as it occurs when reduced from arsenious anhydride (As_2O_3) by charcoal, and condensed while its vapour is still mixed with carbonic oxide, etc., then it oxidizes rapidly on exposure; but if the metal be obtained as a compact whitish mass, such as forms in the parts of the apparatus where the temperature is only just below the point of volatilization of the arsenic, then the metal is scarcely affected by exposure to the atmospere. Under the joint influence of heat and air, arsenic burns with a blue flame, producing arsenious anhydride (As_2O_3). Heated with sulphur, and combination ensues with the formation of the red compound known as "realgar" (As_2S_2). Arsenic frequently occurs in small quantities as an impurity in other metals, as in zinc, copper, tin, antimony, etc., producing hardness and brittleness therein. Its chemical symbol is As, and its atomic weight, 75. The metallic character of this element is not accepted by many chemists, since, in its chemical combinations, it resembles phosphorus and nitrogen, and possesses no basic oxide; yet in physical characters, as lustre, specific gravity, *conductivity* for heat, and electricity, etc., it resembles the metals, especially antimony and bismuth, and it would thus appear to form the connecting link between the metallic and non-metallic elements.

253. Ores.—Arsenic in minute quantities is very widely distributed, occurring occasionally in the *native* state, but more frequently in combination with other metals, as in *arsenical iron;* with *sulphur* as *realgar* (As_2S_2) and *orpiment* (As_2S_3); or in combination with sulphur and iron, cobalt, nickel, or other metals, as it occurs in *arsenical pyrites* or *mispickel* ($FeAs + FeS$); other ores containing arsenic are, *smaltine* or *tin-white cobalt, arsenical cobalt, cobalt glance, nickel glance, arsenical fahl-ores, kupfernickel* or *arsenical nickel, white nickel pyrites* ($NiAs$), *copper nickel* (Ni_2As), and *arsenic bloom.*

254. Preparation.—Arsenic is obtained on the large scale by heating *mispickel* or *arsenical pyrites* (Fe_2AsS) in earthen tubes or retorts, of four or five feet in length, and which are laid horizontally in a long furnace. A nozzle to each tube is formed of sheet-iron, rolled to fit the end of the retort, and to which is luted an earthen receiver. On the application of a moderate heat to such an apparatus, metallic arsenic sublimes as a compact, nearly white, crystalline body, which requires a further purification by resublimation before use, except where intended for the preparation of common alloys, when the crude product so obtained may be directly employed; there remains in the retort, after the operation, a mass of sulphide of iron; thus,

$$Fe_2AsS = Fe_2S + As.$$

At Altenberg, in Silesia, arsenic is prepared by heating in crucibles, surmounted by conical iron caps, a mixture of charcoal and the crude arsenious anhydride (As_2O_3) (obtained as a bye product during the roasting of tin and cobalt ores). Arsenic may also be obtained by heating the sulphides of arsenic with charcoal and potassic cyanide, or with an alkaline carbonate.

255. Arsenious Anhydride.—*Arsenious acid, arsenious anhydride,* or *white arsenic* (As_2O_3), exists either as an amorphous solid, or crystallized in octahedral and rhombic forms. The amorphous variety when first prepared is transparent and vitreous, but on exposure to sunlight it gradually becomes opaque and crystalline; in the vitreous form it may be fused before volatilization, but the crystalline variety sublimes at a temperature of 218° C. (474° F.), without previous fusion. Arsenious anhydride is only sparingly soluble in cold water, but dissolves more readily in boiling water, and is still more soluble in hot *dilute acids*, from which solution the acid separates on cooling. By boiling with nitric acid or aqua regia, arsenious anhydride is converted into *arsenic acid. Carbon, carbonic oxide*, or *hydrogen*, reduce metallic arsenic from arsenious anhydride at a temperature below redness. Arsenious anhydride is also decomposed by nascent hydrogen, yielding arseniuretted hydrogen (AsH_3), a highly poisonous gas; thus,

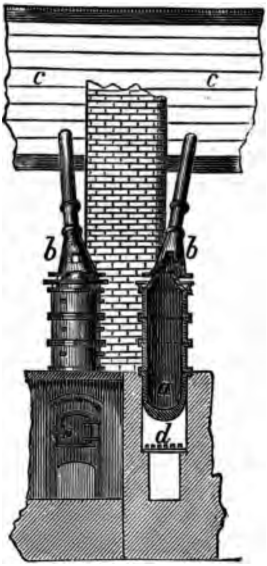
$$As_2O_3 + 12H = 3OH_2 + 2AsH_3.$$

Metallic copper immersed in a hot solution of arsenious anhydride (As_2O_3), or of an arsenite made acid by hydrochloric acid, becomes coated with a grey film of metallic arsenic; zinc behaves in a similar manner, but with zinc a portion of the reduced arsenic combines with the nascent hydrogen, and yields arseniuretted hydrogen, while the residue only of the arsenic is deposited on the zinc. Arsenious anhydride enters into the composition of the brilliant green pigments known as *Scheele's green*, and *Schweinfurt, Emerald or Imperial Green;* the former is an arsenite of copper formed when *arsenious anhydride* or an *alkaline arsenite* is added to a soluble salt of copper, with sufficient ammonia to neutralize the acid. The *Schweinfurt green* is an aceto-arsenite of copper, prepared on the large scale by making five parts of the basic cupric acetate, known as *verdigris*, into a thin paste, and adding it to a boiling solution of four parts of arsenious anhydride in fifty of water, the solution being kept boiling during the mixing of the ingredients and the precipitation of the pigment. The precipitate is then cooled, dried, powdered, sifted, aud rubbed with a little hydrochloric acid, when it is ready for use as a pigment.

Arsenious acid, or anhydride (As_2O_3), is obtained as a secondary product in the roasting of arsenical ores of tin, cobalt, and nickel; also in the roasting of argentiferous native arsenic for the extraction of silver; but the largest supply *is obtained* by the roasting of powdered arsenical *pyrites* or *mispickel*, with access of air, when arsenious anhydride sublimes, and is condensed in long flues or in condensing chambers. If the roasting be performed on the bed of a reverberatory furnace, then the arsenious anhydride, thus collected, will be mixed with carbonaceous matter, and on the resublimation of the product, the carbon with which it is mixed reduces a portion of the anhydride to metallic arsenic, and the final product, instead of being perfectly white, is grey, from the admixture of metallic arsenic; it is hence more usual to effect the roasting in muffle furnaces, which prevent the contact of the flame or fuel with the products of the roasting operation. A furnace of this kind has two floors, one above the other: on the upper floor is spread the ore to be roasted; and a door at the front of this chamber affords access for rabbling the mass, while the fire-bars are at the near end of the lower bed. The products of combustion before reaching the stack are made to pass beneath the upper floor for its full length, and thence backwards along each side of the upper chamber. The upper floor is charged through an opening in the roof, and the arsenious anhydride, with other volatile matters, before reaching the stack pass along flues or long divided passages, which open finally into a large chamber of some 120 feet in height; the condensing flues in Cornwall are 600 feet in length, 6 feet high, and 2½ feet wide, arched over at the top.

At Altenberg, in Silesia, the volatile matters are passed through two or three large chambers, from whence the uncondensed portions are passed through some three tiers of chambers, divided by partitions so as to increase the cooling surface; in these latter, known as the "poison towers," the last traces of arsenious anhydride are deposited, and only the non-condensible sulphurous anhydride (SO_2) escapes to the atmosphere. The chambers are only emptied every one or two months, the workmen, during the operation, being clothed in leather, with their mouths and nostrils protected by wet cloths. The product which is collected from near the stack end of the condensing apparatus is more largely contaminated with arsenious sulphide and other impurities, than that deposited in the earlier parts of the course near the furnace, and the former accordingly requires resublimation.

The resublimation is effected in Silesia in a series of deep cast-iron pots (fig. 67), each of which is charged with about 3 cwt. of the crude acid, and is heated over its own fire *d.* The pot is surmounted by a conical cap *b*, connected with a pipe which conducts the vapours to a large condensing chamber *c*, divided after the manner of our sulphuric acid chambers, and placed well above the subliming apparatus. The joints being all well luted up, a gentle heat is at first applied for about half an hour, when the full heat is attained and is continued for about twelve hours. The arsenious anhydride will then be wholly sublimed into the top portion of the retort, and into the condensing chamber. In Cornwall, a much simpler arrangement is employed, consisting of a cast-iron pot $3\frac{1}{2}$ inches deep and 22 inches internal diameter, with a bottom $3\frac{1}{2}$ inches in thickness; this pot is surmounted by a conical covering about 18 inches in height, and with an opening of about two inches in diameter at its apex; each of these vessels is heated by its own fire-place, or upon a sand bath, when the arsenious anhydride sublimes and condenses in the top of the cone.



Vertical Elevation. *Vertical Section.*

Fig. 67.—REICHENSTEIN ARSENIC REFINING FURNACE.

256. Arsenic Anhydride (As_2O_5) may be obtained by heating its hydrate to dull redness, when it forms a white mass, without action on litmus, nearly insoluble in water, only deliquescent after long exposure, and decomposed at a full red heat into *arsenious* anhydride and free oxygen; it is reduced to the metallic state by carbon, potassic cyanide, etc.

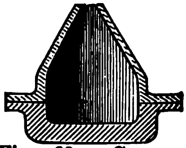


Fig. 68. — CORNISH APPARATUS FOR SUBLIMING ARSENIOUS ANHYDRIDE.

257. *Hydrated* Arsenic Oxide or **Arsenic Acid** may be obtained as a syrupy liquid by treating arsenious anhydride with concentrated nitric acid, this liquid, after standing some time, depositing crystals which are very deliquescent; this acid is now extensively used instead of tartaric acid by the calico printer; it combines with bases forming a class of tribasic salts known as *arsenates*.

258. Sulphur and Arsenic.—The only compounds of sulphur and arsenic of metallurgical interest, are the *disulphide* or *realgar*, and *arsenious sulphide* or *orpiment*.

Disulphide of arsenic or *realgar* (As_2S_2), as already stated, occurs native as an orange-yellow or red mineral, more or less translucent, and possessing a resinous lustre; it occurs, accompanying ores of silver and lead, at Andreasburg, in the Harz, in Transylvania, Hungary, Bohemia, and Saxony. Realgar is prepared, on the large scale, by heating a mixture of arsenical and iron pyrites, collecting the sublimate and melting it with arsenic or sulphur, according to the intensity of the colour required; as thus produced it is amorphous, brown-red in colour, opaque, and burns in the atmosphere with a blue flame, with the production of sulphurous and arsenious anhydrides. This compound is used in pyrotechny, and also as a pigment.

The *trisulphide of arsenic* or *orpiment* (As_2S_3) also occurs native. As prepared for commerce, by the sublimation of a mixture of seven parts of arsenious anhydride (As_2O_3) with one of sulphur, it is translucent, of a lemon-yellow colour, and possesses a resinous lustre. Orpiment is produced as a lemon-yellow precipitate when sulphuretted hydrogen is passed into a solution in dilute hydrochloric acid, of arsenious anhydride or an arsenite. This sulphide melts readily, and volatilizes at a higher temperature; when heated in a glass tube with sodic carbonate or cyanide of potassium and an alkaline carbonate, it yields a mirror of metallic arsenic on the cooler part of the tube; the residue consisting, when sodic carbonate is employed, of sulpharsenate and arsenate of soda, when, if carbon be introduced into the mixture, the arsenate suffers decomposition, and the mirror of arsenic is increased. This sulphide of arsenic constitutes the pigment "King's yellow."

259. Alloys.—Arsenic alloys itself with most of the other metals: with *iron*, *zinc*, *tin*, *gold*, *silver*, *lead*, and *antimony*, it forms alloys which are more or less brittle and hard; it is especially destructive of the malleability of gold, while with copper a white malleable alloy can be obtained. The alloy of arsenic and lead is used in making shot, and in the preparation of some forms of opal glass. Analyses of two specimens of *shot*, published by Dr. Percy,* show it to contain 0·133 per cent. and 0·115 per cent. of arsenic respectively, the same shots containing respectively 0·03 per cent. and 0·284 per cent. of copper. The alloys of arsenic, when heated out of contact with the atmosphere, retain almost the whole of their arsenic, while if heated with access of the atmosphere, part of the arsenic is volatilized as arsenious anhydride (As_2O_3), leaving a residue of a metallic *arsenate* or *arsenite;* but the alloy of *antimony* and *arsenic*, heated in an atmosphere of carbonic anhydride is completely decomposed, with the volatilization of the arsenic. Arsenic lowers the melting point of the metals with which it is alloyed.

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* Percy, Vol. III.

CHAPTER XIV.

BISMUTH.

THIS metal was known to the ancients. Although not of frequent occurrence in nature, it is, however, found associated with the ores of nickel and cobalt in Cornwall and Cumberland, and in the extraction of the latter metals, bismuth is generally obtained as an accessory product.

Bismuth is a greyish-white metal, having a decided reddish tinge, and a bright metallic lustre, which is not sensibly altered by exposure to the atmosphere; but if heated in the air bismuth is readily oxidized, and at a higher temperature burns with a bluish flame, emitting yellow fumes of *flowers of bismuth*. It crystallizes in rhombohedrons, is very brittle, and easily reduced to powder; its specific gravity is 9·779, which, after subjecting the metal to considerable pressure, is reduced to 9·556. Bismuth is strongly diamagnetic; it fuses at 264°C. (507·2°F.), and expands on cooling, so that the density of the metal in the liquid state is greater than in its solid form; at a high temperature it may be volatilized or distilled, and at a white heat it decomposes the vapour of water. Hydrochloric acid has but little action upon the metal, and sulphuric acid only attacks it when hot and concentrated; while nitric acid forms its best solvent, attacking the metal vigorously, with the production of a nitrate of bismuth, which, on dilution with water, precipitates an insoluble basic nitrate of bismuth, and which precipitate, by reduction with black flux at a gentle heat, yields bismuth free from the impurities—arsenic, sulphur, copper, nickel, iron, silver, and gold, which sometimes accompany *commercial* bismuth. Specimens of commercial bismuth occasionally contain as much as 60 oz. of silver per ton of metal. Bismuth can be used instead of lead in the process of *cupellation*, to be described under lead, but is not quite so readily oxidizable as lead. The chemical symbol of bismuth is Bi, and its atomic weight 208.

260. Ores of Bismuth.—As *needle ore* or *bismuth lead ore,* it occurs in Siberia and elsewhere, as *bismuth glance* or *bismuthine* (Bi_2S_3), in Cumberland, Cornwall, Saxony, Sweden, and the United States, and as *bismuth ochre* (Bi_2O_3), along with iron and other impurities, it occurs in Saxony, Bohemia, etc.; while the *native* metal is found in Saxony, Sweden, Norway, Hessia, etc., accompanying the ores of cobalt, silver, lead, copper, and tin; and, as already noted, bismuth occurs associated with the ores of nickel and cobalt in Cornwall and Cumberland.

261. Bismuth with Oxygen and Sulphur.—Bismuth forms three compounds with oxygen, but the most stable oxide is the bismuthous oxide or (as it was formerly termed) teroxide (Bi_2O_3), which occurs as a pale lemon-yellow powder when bismuth is roasted with access of air, or when the subnitrate is gently heated in a crucible. This oxide becomes darker in colour on the application of heat, and fuses at a strong heat forming a glass, which, on cooling, is of a deeper tint than the unfused oxide. Oxide of bismuth is reduced by heating with carbon. The hydrated oxide (Bi_2O_3, H_2O) is precipitated as a white powder when ammonia in excess is added to a soluble salt of bismuth.

Bismuth unites readily with sulphur, upon the application of heat. The tersulphide (Bi_2S_3) is thus obtained as a dark grey solid of metallic appearance; the same sulphide is also obtained as a brown black precipitate when sulphuretted hydrogen is passed through a solution of a bismuth salt.

262. Extraction.—For the purposes of the arts, bismuth is separated by simple *liquation* from the other matters accompanying the metal. The earliest plan adopted for this purpose was to make heaps of the ore and fuel upon the ground; a steady, gentle heat was thus maintained, and the bismuth liquating or sweating out was collected at the bottom of the heap. The supply of bismuth is now derived largely from Saxony, where the metal occurs *native,* associated with ores of cobalt, silver, lead, and tin, in formations of gneiss and clay slate; as also in ores of nickel and cobalt, with arsenic. At Schneeberg, in Saxony, the cobalt ores, containing about twelve per cent. of bismuth, are first crushed and then subjected to liquation in the furnace shown in fig. 69, consisting of an arched chamber, in which are arranged a series of iron tubes or retorts, inclining from back to front. Beneath the retorts is the fireplace, and in the roof of the furnace are two holes over each retort, which can be opened and closed as required for the proper regulation of the draught. At the back of the furnace, and from the upper end of the retorts, the brickwork forms a slope downwards to a trough filled with water, into which the residues from the retorts are withdrawn after the conclusion of the liquating process. The lower end of each retort is closed with an iron plate, or with a fireclay stopper, containing a small aperture at its lowest point, through which the melted bismuth passes into the iron basins as shown, and where it is kept in a state of fusion by a fire beneath the dishes, while the surface of the metal is kept from oxidation by a covering of small charcoal. Wood is the fuel usually employed in this furnace, but gas has also been applied to it.

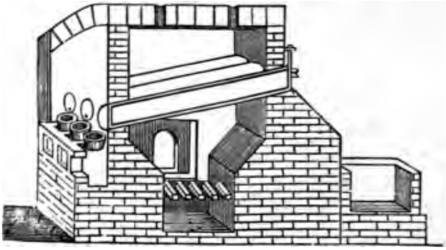

Fig. 69.—Bismuth Liquation Furnace.

The retorts are each charged from the upper end, with about 56 pounds of ore, when, if the furnace be hot from the working off of a previous charge, the metal will begin to pass out at the bottom in about ten minutes after charging; a gentle fire is maintained on the grate, a *low* temperature, about 265° C., sufficing for the liquation of the metal; and to facilitate the passage of the melted metal towards the lower end, the charge is moved about by a small rake introduced through the door at the upper end of the retort, and in about forty minutes from the commencement the whole of the bismuth will have separated from the gangue and other metalliferous matters which accompany it. The residues are then raked out at the back, and slide down the incline into the water trough. The metal collected in the basins is then ladled out into moulds, forming bars of from 20 lbs. to 50 lbs. in weight.

At Joachimsthal,[*] Vogel treats bismuthic ores of nickel and cobalt (containing from 10 per cent. to 30 per cent. of bismuth) with from 25 per cent. to 30 per cent. of their weight of small pieces of iron, along with 15 per cent. to 50 per cent. of carbonate of soda (according to the amount of gangue present), 5 per cent. of lime, and 5 per cent. of fluor spar. This mixture is introduced into crucibles some 23 inches in height and 16 inches in diameter, which are heated in wind furnaces, when the bismuth separates and forms a layer in the bottom of the crucible, above which is a stratum of *speiss* (a metallic-looking compound containing nickel, cobalt, iron, arsenic, and sulphur, with traces of other metals). The bismuth, after again fusing, is ladled out into conical moulds.

The metal thus obtained is often impure, containing sulphur and traces of arsenic, copper, nickel, iron, and lead, with variable amounts of silver; if required pure, the commercial metal must be treated, as already described, with nitric acid. It is freed from sulphur and arsenic, but not from lead, iron, or silver, by fusing it with about one-tenth of its weight of nitre, and continually stirring the mixture during the fusion. By this treatment the impurities collect as a slag on the surface of the metal, and, if necessary, the fusion with nitre must be repeated a second time. The silver can be separated by *cupellation*, and the oxide of bismuth so produced subsequently reduced by charcoal in earthen crucibles.

263. Alloys.—The effect of bismuth when alloyed with other metals is usually to form with them more or less readily fusible bodies, which expand on solidification after fusion. The alloy known as *fusible metal* which melts at about 93·75° C., or below the boiling point of water, consists of equal parts of lead and tin, with two parts of bismuth, and owing to the expansion of this alloy during cooling, it is much used for taking casts or copies of dies and other bodies. The addition of a small amount of cadmium to this alloy, constitutes it what is known as "Wood's alloy," which melts at a still lower temperature, viz., 82°C., or 180°F.

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[*] *Kerl. Handbuch* der Metallurgischen hüttenkunde.

An alloy of two parts of lead with one of bismuth fuses at 116° C., is ductile, and may be rolled without cracking (Berthier). An alloy of three parts of lead with two of bismuth is said to have about ten times the tenacity of lead alone. The density of these alloys is above the mean of the constituent metals.

Bismuth and mercury amalgamate by simple trituration at the ordinary temperature, the amalgam retaining a considerable amount of bismuth without losing its fluidity; mercury and bismuth, gently heated together, also yield a fluid alloy if the bismuth be not in too large quantity; with two parts of mercury to one of bismuth the amalgam is pasty, and after standing hardens, and becomes more or less crystalline. The adulteration of mercury by bismuth may be detected by shaking the metal with air, when, if bismuth be present, a crystalline black powder separates.

Arsenic or antimony, when alloyed with bismuth, yield products which are brittle, and expand considerably on cooling.

Equal parts of bismuth and silver, when fused together, yield a brittle, scaly alloy, of a reddish tinge, which may be cupelled with the separation of the whole of the bismuth as bismuthic oxide, exactly as with lead. In the same manner cupellation of the alloy of gold and bismuth may be effected.

Bismuth is a constituent of Britannia metal, as detailed when speaking of alloys of tin, an inferior kind known as "Queen's Metal," consisting of 75 per cent. of tin, 8·5 per cent. of antimony, with 8·5 per cent. of lead, and 8 per cent. of bismuth; and pewterer's solder consists of equal parts of lead and bismuth alloyed with two parts of tin.

The presence of only ·6 per cent. of bismuth in copper is sufficient to make the metal crack in the edges on rolling.

CHAPTER XV.

PLATINUM.

THIS metal ranks next to silver in whiteness, and when polished it has a very strong metallic lustre; it is very malleable and ductile, being only inferior to gold, silver, and copper in malleability, and to gold and silver in ductility, while in tenacity it is only exceeded by iron and copper The pure metal is softer than silver, it does not oxidize by exposure to the atmosphere at any temperature, and expands less by heat than any other metal; hence its employment for fusing into glass in the manufacture of philosophical and other instruments requiring the insertion of metallic connections through the substance of the glass; while in conductivity for heat and electricity it is much inferior to either gold or silver, in this respect ranking about equal with iron. It is infusible in the strongest heat of a smith's fire, but may be fused by the electric current, or by the oxyhydrogen blowpipe; at a high temperature the metal can be *welded* by pressure or hammering, as is exemplified in the condensation and welding together of the particles of spongy platinum; and with the exception of osmium and iridium, it is the heaviest of all known substances, its specific gravity varying from 21·25 to 21·5, according to the mechanical treatment it has received.

Platinum resists the action of most chemical agents, it is not attacked by hydrochloric, sulphuric, nitric, hydrofluoric, or any other single acid, except when alloyed with a large proportion of silver, under which circumstances it is soluble in nitric acid, a quality made use of in the assay of gold, for the separation of the platinum with which the gold is frequently alloyed; in nitro-hydrochloric acid (*aqua regia*), platinum dissolves slowly. These qualities of withstanding the action of chemical agents, coupled with the power of resisting high temperatures, together with its non-oxidizability at all temperatures, make it a valuable material for the construction of crucibles, dishes, foil, wire, etc., used in the chemical laboratory for blowpipe and other experiments, as also for the manufacture of the *stills*, *syphons*, etc., employed in the concentration of sulphuric acid; and of the vessels employed in the method of *parting* gold and silver by sulphuric acid, as described under these metals. From its power of resisting corrosion, it has been used for the touch-holes or vents of rifles and large ordnance, but its cost prevents its general adoption for this purpose. The hammered metal is only slowly attacked when strongly heated with sulphur; but phosphorus or arsenic under like conditions unite with the metal, with the formation of a readily fusible compound.

A mixture of silica and carbon cannot be exposed to a high temperature in platinum vessels, since the reduced silicon attacks the metal rapidly, with the formation of a fusible silicide of platinum; and for the same reason platinum vessels are never heated in contact with coke or charcoal, which always contain more or less silica, but are either heated in a gas flame, or, if required to be inserted into a coke fire, are enclosed in a receiver of some refractory material, as magnesia, etc.; nitre, caustic alkalies, alkaline earths, and acid potassic sulphate also attack it at high temperatures. Like silver, it absorbs oxygen when in the fused state, liberating it again as it cools, and if cooled rapidly, it *spits* or *sprouts* like silver (Deville and Debray) under the same circumstances. Platinum possesses the remarkable property of effecting the combination of oxygen and hydrogen, and of some other combustible gases into mixtures of which it is introduced, but this quality, known as *catalysis*, is more powerfully exercised by the metal in its *spongy* form, or as *platinum-black;* it forms two oxides, chlorides and sulphides, none of which are, however, of metallurgical importance. The chemical symbol of platinum is Pt, and its atomic weight is 197·4.

264. Platinum-black.—Platinum in an extremely fine state of division forms a black powder known as platinum-black, which resembles lamp-black in appearance, and in which form it possesses some most remarkable and powerful chemical qualities. Platinum-black soils the fingers, and is not altered by exposure to a red heat, but by heating to whiteness it assumes the metallic appearance of the ordinary or hammered metal, and no longer soils the fingers; in its finely divided state it absorbs and condenses gases within its pores, with the evolution of considerable heat, and if introduced into a mixture of oxygen and hydrogen it gives rise to their immediate combination; it likewise promotes in a remarkable manner the oxidation of alcohol or wood-spirit, when moistened with these and exposed to the atmosphere, producing therefrom acetic and formic acids respectively. Platinum in this form, as also *spongy* platinum, is rapidly attacked when somewhat strongly heated with sulphur, while the hammered metal is but very slowly attacked by the same treatment.

Platinum-black is obtained as a black powder when alcohol is cautiously added to a solution of platinous chloride ($PtCl_2$) in a hot solution of potash, the reaction being attended with a copious and violent liberation of carbonic anhydride (CO_2); the black precipitate so obtained requires washing with alcohol, afterwards with hydrochloric acid and potash, and lastly with water. This body is also obtained when a solution of platinic chloride ($PtCl_4$) is boiled with sodic carbonate and sugar; or by precipitation with zinc from a solution of platinic chloride containing an excess of hydrochloric acid.

265. Spongy Platinum.—This is the name applied to the spongy, slightly coherent form of metallic platinum, obtained by heating to redness the yellow double chloride of platinum and ammonium ($2NH_4Cl, PtCl_4$), precipitated on the addition of ammonic chloride (NH_4Cl) to a solution of platinic chloride; which precipitate, on the application of heat, gives off chlorine and ammonic chloride, and there remains a residue of *spongy platinum.* By the application of pressure to this substance when at a full red heat, its particles may be *welded* together, when it assumes the form and appearance of commercial platinum. Like the other forms of platinum, it is capable of *inducing* chemical combination in the mixtures of certain combustible gases; at a strong red heat it unites with sulphur and phosphorus, and may also be alloyed with most other metals on the application of heat.

266. Occurrence of Platinum.—Patinum is a comparatively rare metal, which, like gold, always occurs in the *native* state, and it very frequently accompanies the latter in alluvial sands, gravels, and debris of the earliest geological formations, but, unlike gold, it does not frequently occur in large masses or nuggets, though such have been found weighing upwards of twenty-two pounds each; the more general form of its occurrence is, however, as rounded or flattened grains of a light steel-grey colour and metallic lustre, occurring, as already noted, in alluvial deposits, detritus, and auriferous sands, accompanied with magnetic iron ore, corundum, and occasionally chrome iron ore, zircon, spinel, serpentine, and augitic debris; when after the separation, by careful washing operations, of much of the sandy, earthy, and lighter portions of the ore, there remains a residue consisting of grains of platinum, along with gold, magnetic iron ore, corundum, and an exceedingly heavy alloy of osmium and iridium, and from this residue the gold, if present in considerable proportions, is separated by amalgamation, while the magnetic iron ore may be removed by the magnet. The *native* metal is never pure, containing only from 70 to 85 per cent. of platinum, the remainder consisting of *iron*, forming occasionally as much as 13 per cent. of the ore, *palladium* to the extent of from ½ to 1 per cent., with *iridium*, *rhodium*, *osmium*, *ruthenium*, and *copper*, with frequently *gold* and *silver*, and occasionally *lead* and *manganese*. The chief localities of the occurrence of this metal are Russia (in the districts of the Urals), Brazil, Mexico, Peru, Borneo, California, Oregon, St. Domingo, Siberia, Australia, etc., and also in small quantities in certain copper ores occurring in the neighbourhood of the Alps.

267. Extraction.—The *wet methods* of extracting platinum were, until within a few years ago, the only ones adopted for the separation of this metal from the other metals, osmium, iridium, palladium, etc., with which it is always alloyed in nature, the very refractory nature of platinum rendering it impossible to effect the separation and refining of the metal by methods of fusion, until Deville and Debray succeeded, by means of the oxyhydrogen flame, in melting the metal on a bed of lime, in quantities of twenty pounds and upwards.

In the separation of platinum by the "**wet method,**" the ore, after careful and complicated washings, and separation of the gold by amalgamation, is first treated with nitric acid, by which silver, copper, iron, and lead, are extracted; the residue, after washing with water, is digested at a gentle heat with hydrochloric acid, to which is added at intervals small quantities of nitric acid, the digestion being continued so long as the acid dissolves anything further. The liquid is then evaporated to the consistency of syrup, to expel the excess of nitric acid; it is then diluted with water and drawn off, after which the residue is again treated in the same manner with fresh acid, the operation being repeated so long as anything is extracted by the acids. The red solution thus obtained contains the chlorides of platinum, palladium, rhodium, and some iridium, while the residue in the retort consists of grains and plates of an alloy of osmium and iridium, along with quartz, corundum, and other foreign insoluble matters occurring with the ore.

To separate the palladium the solution is boiled, by which the tetrachloride of palladium is reduced to the state of dichloride, when, on the addition of potassium chloride, the sparingly soluble yellow double chloride of platinum and potassium is precipitated; or in the presence of iridium, the precipitate is red in colour and contains in addition the double chlorides of iridium and potassium. The separation of the last portions of the iridium is attended with considerable difficulty; but for this purpose the precipitated chlorides, after well washing, are ignited with twice their weight of potassic carbonate, by which the platinum is reduced, and the iridium converted into trioxide, when, after dissolving out the potassium salts, the residue is again treated with aqua regia, by which the platinum is dissolved, while the oxide of iridium is, to a large extent, left in the residue. To complete the elimination of the iridium, it may be necessary to repeat the precipitation with potassium chloride, and ignition with potassic carbonate, several times, after which ammonic chloride (sal-ammoniac) is added to the solution of platinic chloride thus obtained, when the double chloride of platinum and ammonium ($2\,NH_4Cl, PtCl_4$) so precipitated is washed, dried, and ignited in a black lead or plumbago crucible, when a black powder remains, which is platinum in its *spongy* form.

If the presence of a small amount of iridium be not of importance for the purpose to which the metal is to be applied, then the two metals are precipitated together in the first instance after the solution of the ore in nitro-muriatic acid, by ammonic chloride instead of by potassium chloride, and the precipitate so obtained may be at once ignited for *spongy platinum.*

For application in the requirements of the arts and manufactures, the metal still requires conversion into a coherent and workable form, for which purpose the particles of the fine powder thus obtained require to be *welded* together for the production of a solid malleable metal, an operation until recently accomplished by subjecting it to the combined action of heat and pressure in the following manner, as introduced by Dr. Wollaston. The spongy platinum being reduced to as fine and uniform a powder as possible (by gently rubbing it between the hands, and afterwards in a wooden mortar), is sifted through a fine lawn sieve, and, after separation of the coarser particles, it is made into a thin uniform paste or mud with water, and introduced into a conical brass cylinder, about 6·75 inches in height, by 1·12 inch in diameter at the top, and 1·23 inch at the bottom, to the bottom end of which is fitted a steel plug, entering the cylinder for a length of about ·25 inch, and covered over with bibulous paper to facilitate the drawing off of water from the cylinder. The cylinder, well greased internally, is filled with water, and introduced into another vessel also filled with water, where the cylinder is completely filled with the platinum paste, the latter displacing the water in the cylinder; the surface of the paste is covered with blotting paper, succeeded by a woollen cloth, and after pressing out a portion of the water, by the pressure of the hand applied to a wooden plug, a copper plate is placed on the surface, and the cylinder so prepared is introduced into a powerful horizontal lever press, where it is subjected to considerable pressure, whereby the water is to a very large extent expelled, and the spongy metal is compressed into a coherent, somewhat porous cake, which is then extracted by withdrawing the plug from the bottom of the cylinder.

The cake of metal is now heated upon a charcoal fire, for the expulsion of grease and any water it may still retain, from whence it is transferred to a wind furnace, where the cake is placed upon its edge and heated during twenty or thirty minutes to an intense heat, when, after allowing the temperature to fall slightly, it is removed, while still at a white heat, and further condensed by careful hammering upon its ends, but never upon the sides, otherwise the metal will crack in the operation; after this treatment the particles are found to be *welded* together, and the metal is obtained in the malleable and ductile form required for use in the arts. The ferruginous scale with which the metal is often covered, after the last manipulation, is cleaned off by coating it over with a mixture of borax and cream of tartar or potassic carbonate, then it is covered over with an earthen pot, and inserted on a platinum tray into an air furnace, when, after the metal has attained a red heat, it is withdrawn and at once introduced into dilute sulphuric acid, by which its surface is perfectly cleaned.

To *refine* the metal, increase its density, and free from the pores, etc., which the metal, as prepared by the above method of Wollaston, is liable to contain, Deville and Debray have introduced a furnace (fig. 70) in which the metal may be melted and poured out from the lip *a* into moulds for the casting of ingots. This furnace also effects the removal of any small quantities of osmium and silicon which the platinum may have retained, the former as an oxide, which is volatilized, while the latter forms a fusible calcic silicate, which is absorbed by the lime of the walls of the furnace, and any traces of palladium, lead, silver, or gold that might have remained with the platinum are also removed, probably by volatilization, during this operation. The furnace (fig. 70) is an oxyhydrogen furnace, formed of two blocks of lime *d*, *e*, placed together, as shown, and braced around with bands or wires of iron, to prevent the breaking down of the furnace by the cracking of the lime. The metal to be melted is placed on the hollow cavity of the lower block *d*, and one or two apertures, according to the capacity of the furnace, are made in the upper block for the introduction of the jet or jets of the oxyhydrogen blowpipe. The pipe *b* supplies hydrogen or coal gas, while *c* is connected with a gas-holder containing oxygen, which it introduces, at a pressure of from 16 to 20 inches of water, along the pipe shown, into the centre of the hydrogen flame, the hydrogen being ignited before the oxygen is turned on, and in this manner a temperature can be obtained sufficient to melt platinum readily, from 40 to 60 minutes sufficing to melt and refine from 20 to 30 lbs. of platinum, which is then cast by pouring the metal from the lip *a* into moulds of gas coke, or into iron moulds lined with platinum.

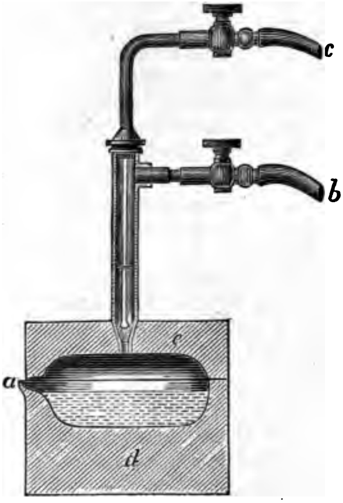

FIG. 70.—LIME FURNACE FOR MELTING AND REFINING PLATINUM.

To supersede the method of welding together the particles of spongy platinum by the method of Dr. Wollaston, and to obtain a more dense and uniform metal than that process affords, Messrs. Deville and Debray also introduced the furnace illustrated in fig. 71, which is simply for melting platinum for the purpose of casting it into ingots, without exercising the refining action possessed by the last described or lime furnace. This apparatus consists of a crucible of gas-coke, containing the spongy platinum to be melted; this is enclosed within another crucible of lime, fitted with a conical cover, also of lime. The compound crucible so formed rests on a small stand or block of lime, while the furnace proper consists of three blocks of lime, one of which forms the base, while the second, which rests upon the first, is bored to the form of a cylinder, and measures about 4½ inches in height, and has four apertures around its base for the escape of the flame and products of combustion. The top of the furnace consists of a somewhat thicker slab of lime, perforated with a conical opening for the introduction of the oxyhydrogen jet, in the manner described for fig. 70, the several blocks of lime being *each* strengthened and held together by iron

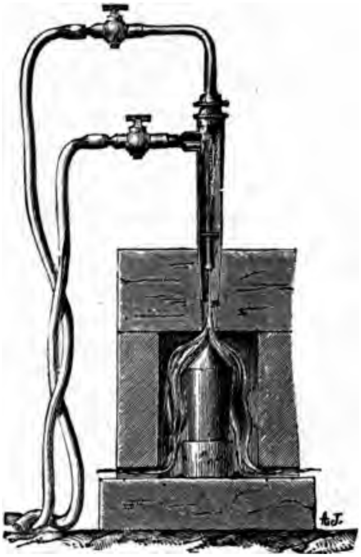

Fig. 71.—Furnace for Melting Platinum.

wires, to prevent their breaking down under the influence of the intense heat. In this furnace, ingots of commercial platinum weighing upwards of 2 cwt. have been melted.

Other *wet methods* have been proposed by W. von Schnieder, M. Döbereiner, etc., for the separation of platinum from osmium, iridium, and other metals of the platinum group contained in the solution of their mixed chlorides, obtained by the treatment of the platinum ore with *aqua regia.* W. von Schnieder proposes to boil the solution with an excess of caustic soda, free from potash, whereby the several metals, with the exception of platinum, are converted into lower chlorides, not precipitable by ammonic chloride, while the platinic chloride ($PtCl_4$) is scarcely affected by the treatment, and may be precipitated by the addition of ammonic chloride, and obtained in the form of spongy platinum, in the manner previously described. A like effect, but effecting the separation less completely, is produced by treatment with calcium hydrate in lieu of caustic soda, and this constitutes Döbereiner's method of purifying platinum.

Messrs. Deville and Debray have introduced a "dry method" for the extraction of platinum from its ores, by which a nearly pure, very malleable and ductile metal is obtained, though not so pure as that prepared by the "wet process." In the extraction of platinum by the "dry method," an alloy of lead and platinum, or a platiniferous lead, is first prepared, from which alloy the lead is largely separated by the ordinary methods of cupellation in a cupel of bone ash;* but in this case the cupellation requires completion on the bed of the oxyhydrogen furnace (fig. 70), since, as the lead is oxydized and removed, the alloy becomes more and more infusible, and the high temperature produced in this furnace is necessary to melt it. The alloy of platinum and lead is prepared by introducing some 2 cwt. of platinum ore (previously freed as completely as possible from earthy matter, etc., by repeated washing), along with half of its weight of galena (PbS), into a small reverberatory furnace, of which the bed is hollowed out, and formed of fire-brick *lined* with clay, the charge being introduced in small quantities at a time, on to the red-hot bed of the furnace, thorough mixture being maintained by repeatedly stirring the charge with iron bars, and a metalliferous matt thereby results. A quantity of a difficultly fusible glass is now added, which forms a flux or covering to the surface of the matt, and an amount of litharge (PbO), equal to the weight of the galena (PbS), is gradually added. The oxide and sulphide of lead react upon each other, whereby sulphurous anhydride is evolved, and metallic lead is separated, which alloys with the platinum without taking up the osmium and iridium. The two latter form a heavy osmium-iridium alloy, which gradually subsides on allowing the bath to remain undisturbed, thus forming a layer on the bottom of the furnace, above which floats the fluid alloy of platinum and lead. After allowing the bath to remain at rest some time to allow of the more perfect separation of the osmium-iridium alloy, the platiniferous lead is ladled out and cast into ingots, while the residue remaining on the bottom is again added to a subsequent charge.

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* For a description of the process of cupellation, see the Chapter on Lead and Silver in Vol. II.

The platiniferous lead thus obtained is now subjected to cupellation upon a test or cupel, in the ordinary manner of cupellation, whereby the lead is removed as litharge, which melts, is absorbed by, and passes through the substance of the test, while the platinum is left on the cupel as a crude spongy mass, retaining small portions of lead, osmium, iridium, and rhodium. This alloy is transferred for *refining* and *fusion* on to the lime hearth of the oxyhydrogen lime furnace represented in fig. 70. After this treatment the metal still retains traces of iridium and rhodium, which have the effect of rendering the metal a little harder and less fusible, or better adapted to most of its applications in the arts.

268. Alloys of Platinum.—Under the influence of heat, platinum will alloy with most of the other metals, producing bodies which are usually considerably more fusible than platinum itself, and for this reason the melting of metallic bodies in platinum vessels is to be carefully avoided. Thus, on the application of heat, platinum unites with *antimony* or *arsenic*, the union being attended with incandescence and the production of brittle and readily fusible alloys; with *bismuth*, also, union takes place readily, but without incandescence and the alloy is again brittle and readily fusible;

but if these alloys be heated in the air continuously for some time, almost the whole of the antimony, arsenic, or bismuth is oxidised, and a residue of platinum remains.

Platinum alloys with *iron* and *steel*, producing bodies more or less difficultly fusible, according to the proportion of platinum present; with equal weights of the two metals the alloy requires the heat of the oxyhydrogen blowpipe for its fusion, whilst with but 1 per cent. of platinum a steel may be produced, which is readily melted in the ordinary furnaces (see page 79).

Gold and platinum alloy together, with the formation of alloys which approach more or less to the colour of gold, as the proportion of the latter is increased, and with the increase in the amount of gold, the melting point of the alloy is also lowered.

Lead and platinum combine very easily with the production, if the proportion of lead be considerable, of readily fusible alloys, the fusibility decreasing with an increase in the amount of platinum present.

Platinum and *silver* alloy well together, small proportions of the former rendering silver harder and less white. The silver may be extracted from this alloy by boiling sulphuric acid; while nitric acid, if the silver be present in considerable quantity, dissolves both metals.

The most important alloys of platinum, for the purposes of the arts and manufactures, are those with the rarer metals *iridium* and *rhodium*, with which platinum always occurs associated, and the perfect separation of which is attended with considerable trouble and expense, while for many purposes the alloy of these three metals is better adapted than is the pure metal itself, since the alloy is harder, less fusible, and less easily attacked by chemical reagents. In the preparation of this alloy it is only necessary to fuse the ore along with 4 or 5 per cent. of lime in the oxyhydrogen flame, for which purpose a bed of lime is required (fig. 70) to hold the fused alloy, and to absorb the fusible slags produced by the oxidation of the *copper* and *iron* present in the ore of platinum, while the *palladium* and *osmium* originally present are volatilized at the high temperature employed.

An *amalgam* of platinum of a silvery appearance may be obtained by triturating the spongy metal with mercury in a warm mortar, the union being promoted by moistening the mixture with water acidified with acetic acid, and from this amalgam the mercury is expelled on the application of heat, and a residue of platinum is deposited. The hammered or compact metal does not amalgamate with mercury. The amalgam containing 12 per cent. of platinum, is metallic in appearance, and possesses a soft greasy feel, the solidity of the substance increasing with the proportion of platinum, until with from 40 per cent. to 45 per cent. of platinum, the amalgam assumes the form of a dark grey solid.

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